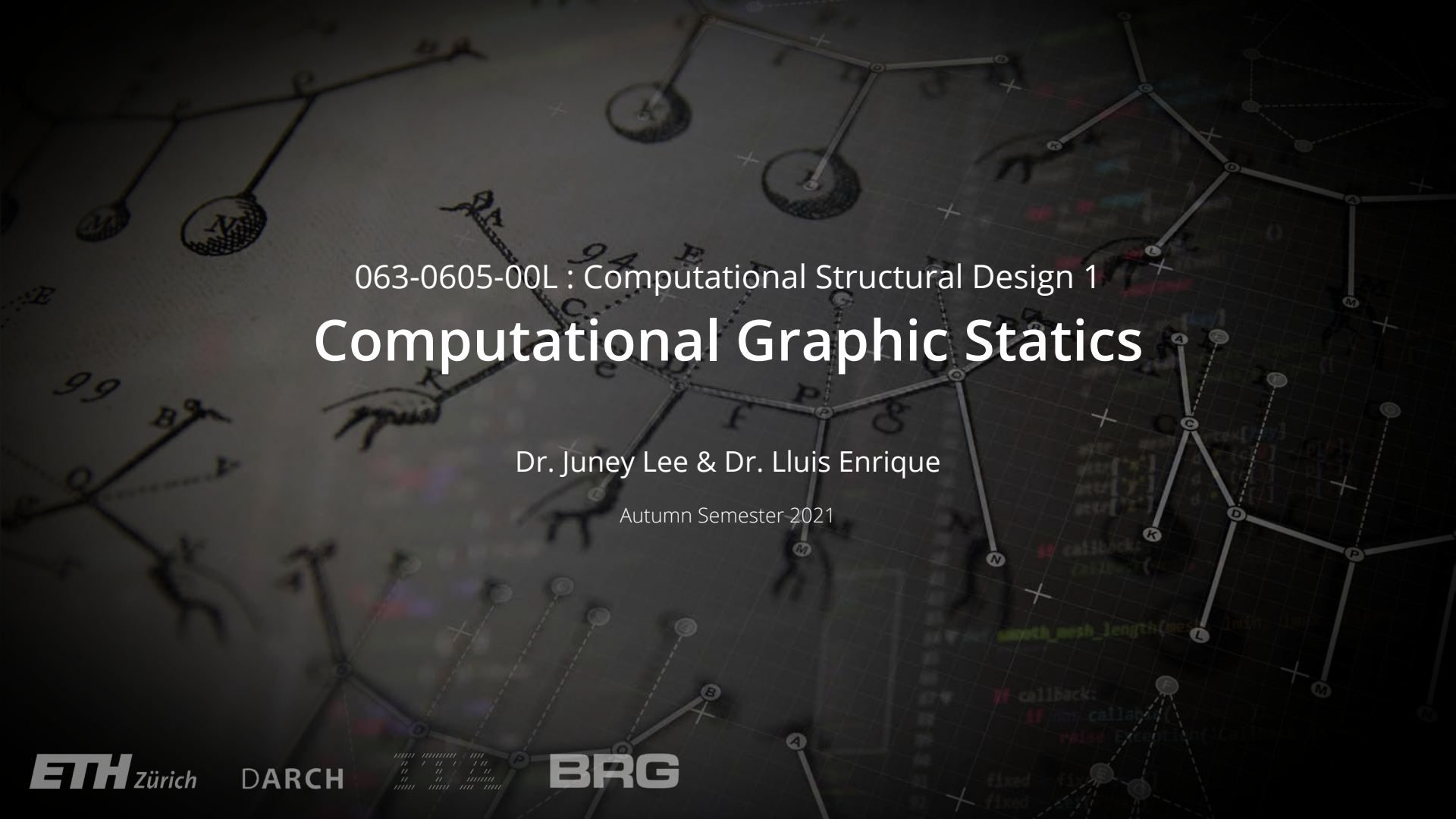

063-0605-00L : Computational Structural Design 1

Computational Graphic Statics

Dr. Juney Lee & Dr. Lluis Enrique

Autumn Semester 2021

ETH Zürich DARCH BRG


BRG
http://block.arch.ethz.ch
@blockresearchgroup







FIRST
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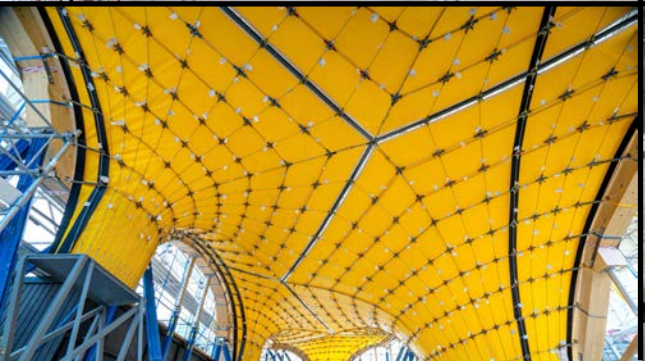
Ideas-City.org



BRG

Lecturers

Dr. Juney Lee

Dr. Lluis Enrique

PhD student instructors

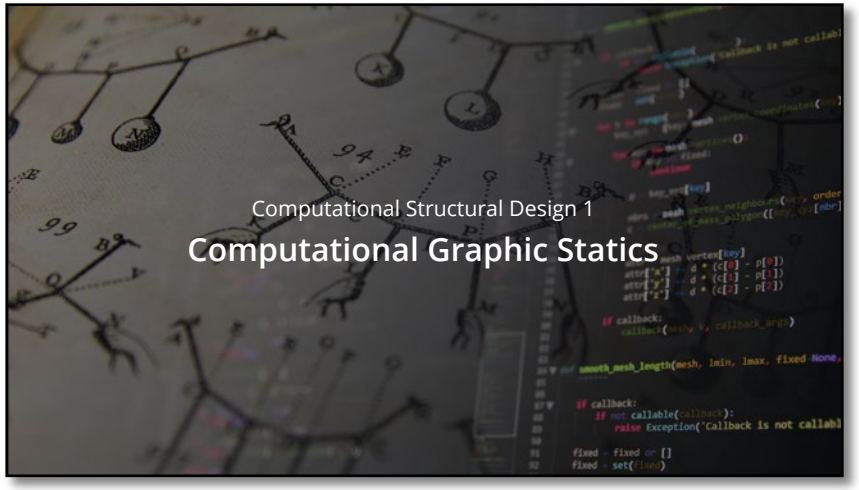
Lotte Aldinger

Ricardo Avelino

Teaching assistant

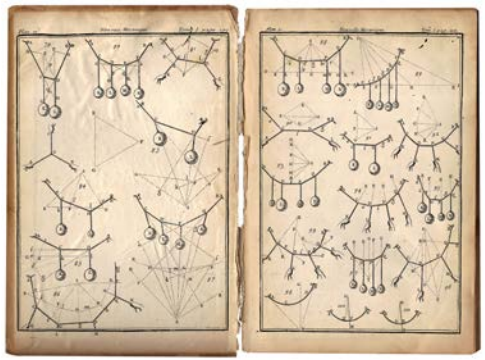
Kerstin Spiekermann

Michele Capelli



Fall 2021

Spring 2022



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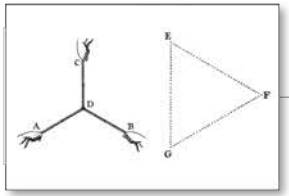
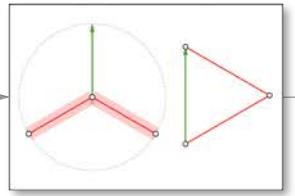
Explore new **structural design opportunites**

by combining **graphic statics** with **computational tools**

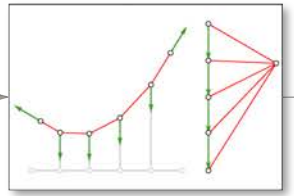
2D **2.5D** **3D**



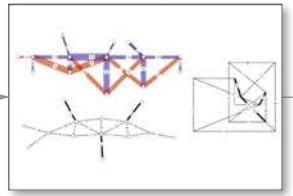
Module I
Basics of Graphic Statics



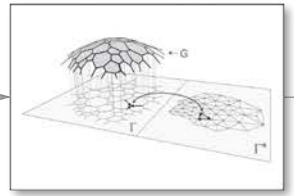
Module II
Interactive Graphic Statics I (single node)



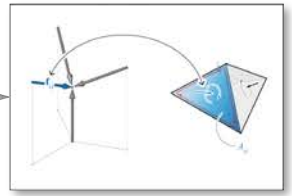
Module III
Interactive Graphic Statics 2 (multi node)



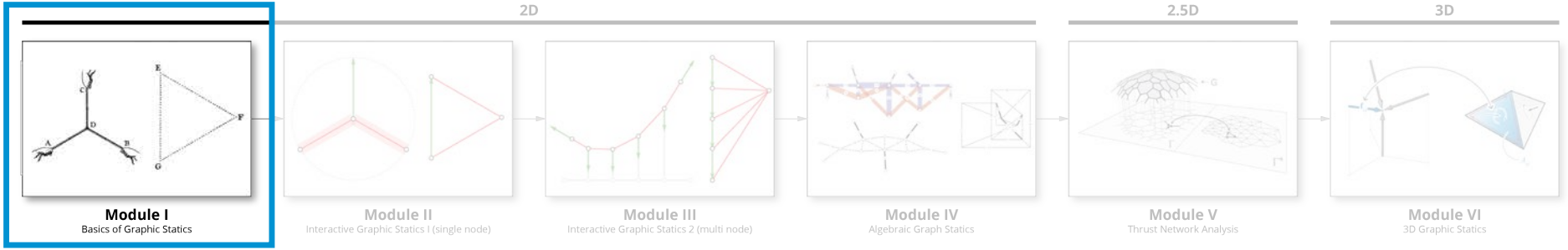
Module IV
Algebraic Graph Statics



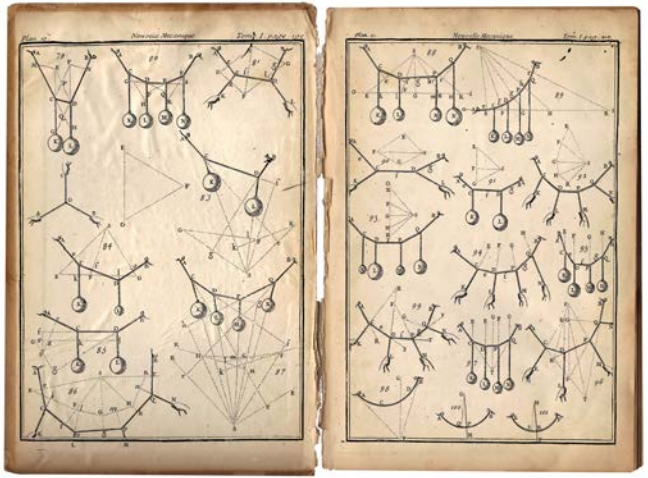
Module V
Thrust Network Analysis

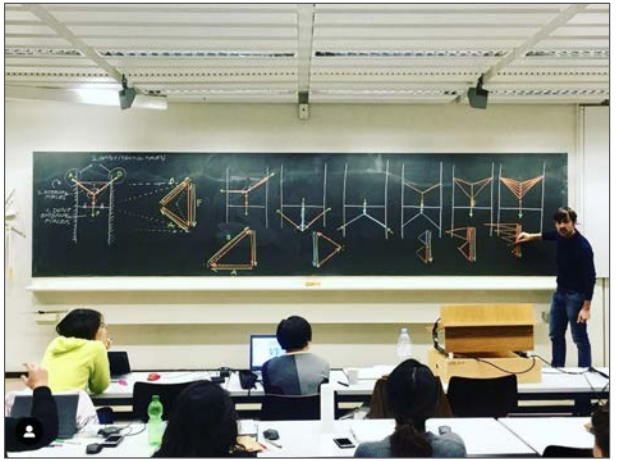


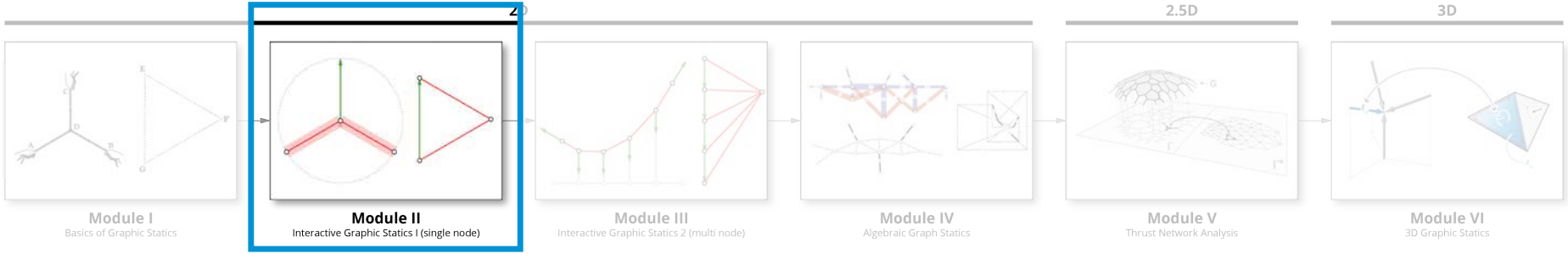
Module VI
3D Graphic Statics



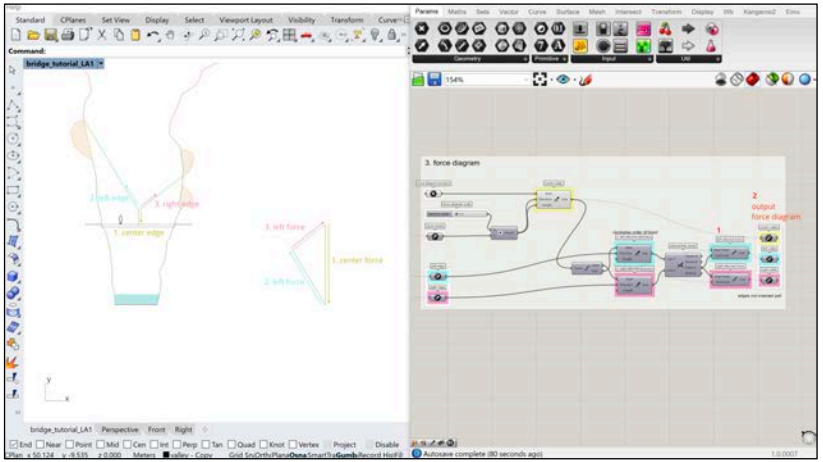
Module I · Basics of graphic statics

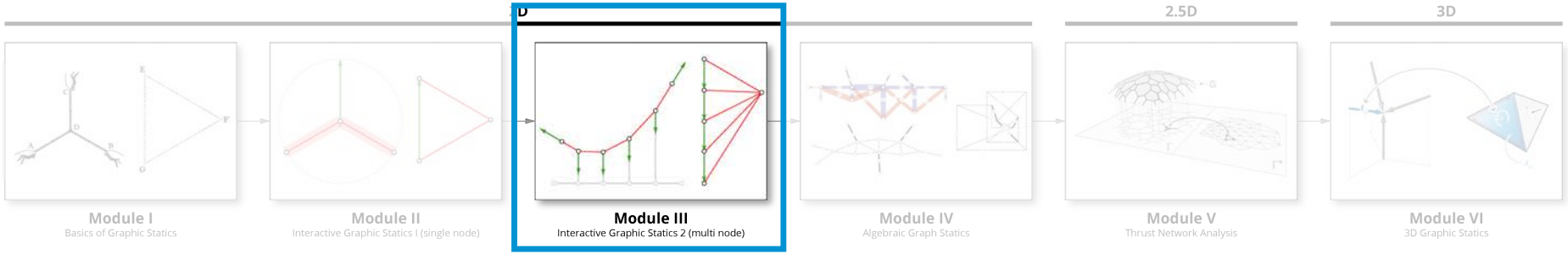




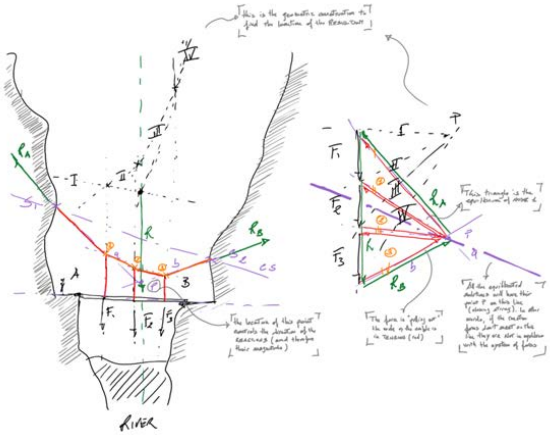


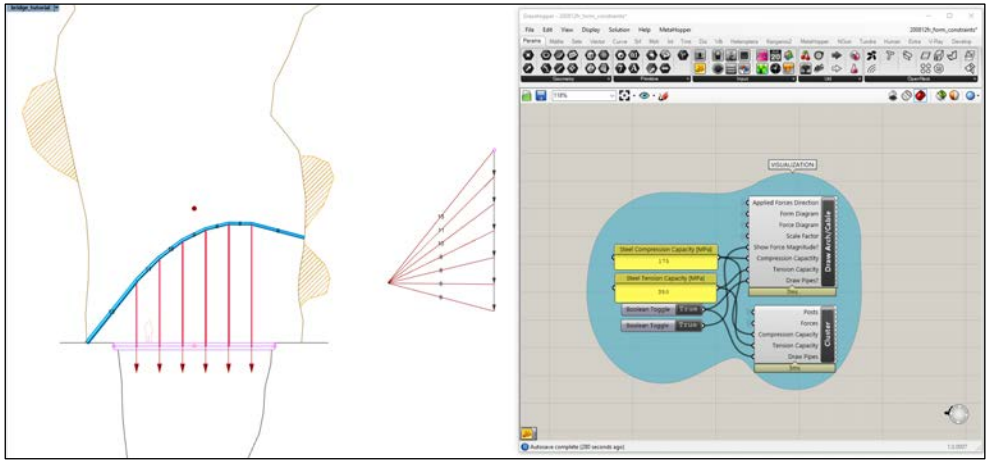
Module II · 2D procedural graphic statics 1

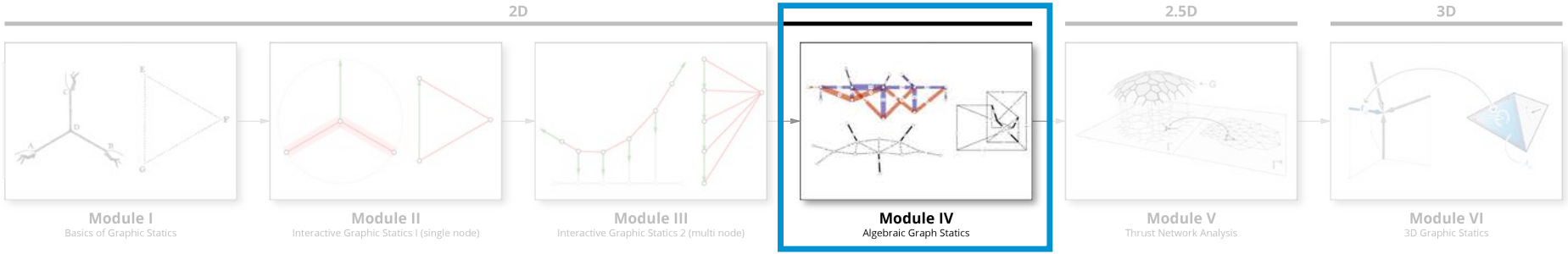




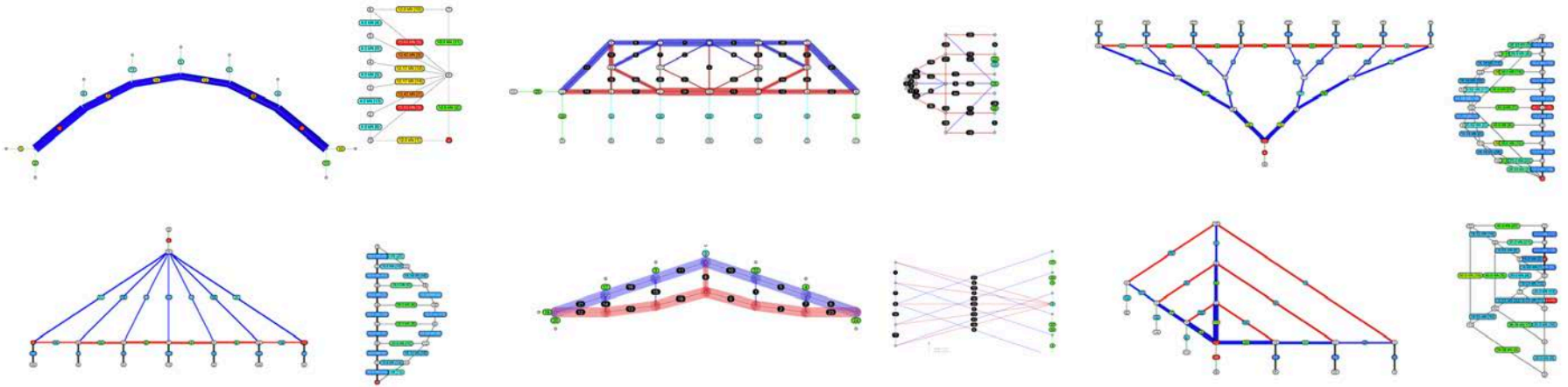
Module III · 2D procedural graphic statics 2

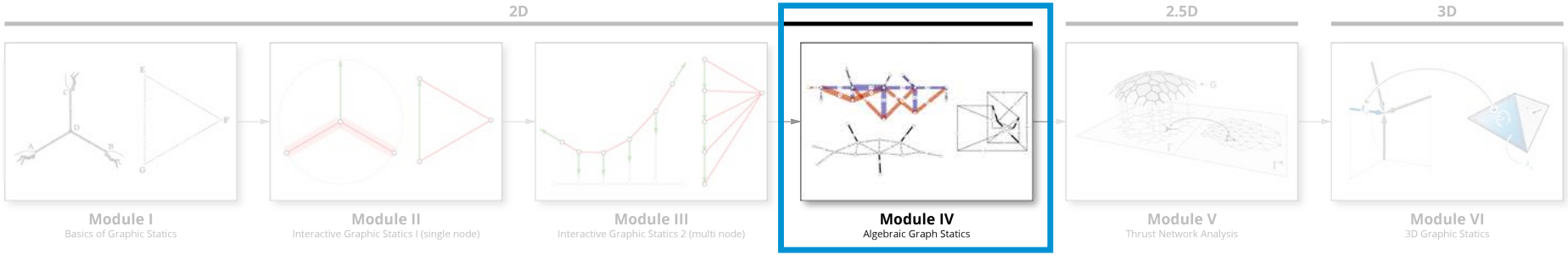




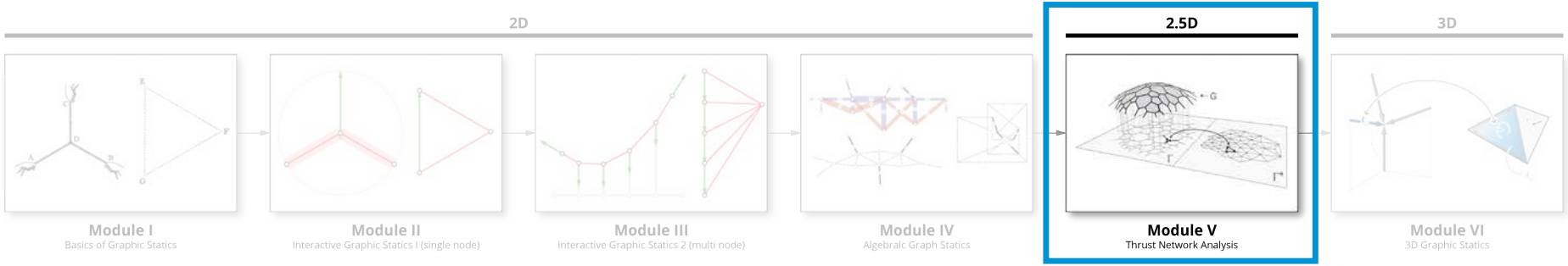


Module IV · Algebraic graph statics (automatic construction)

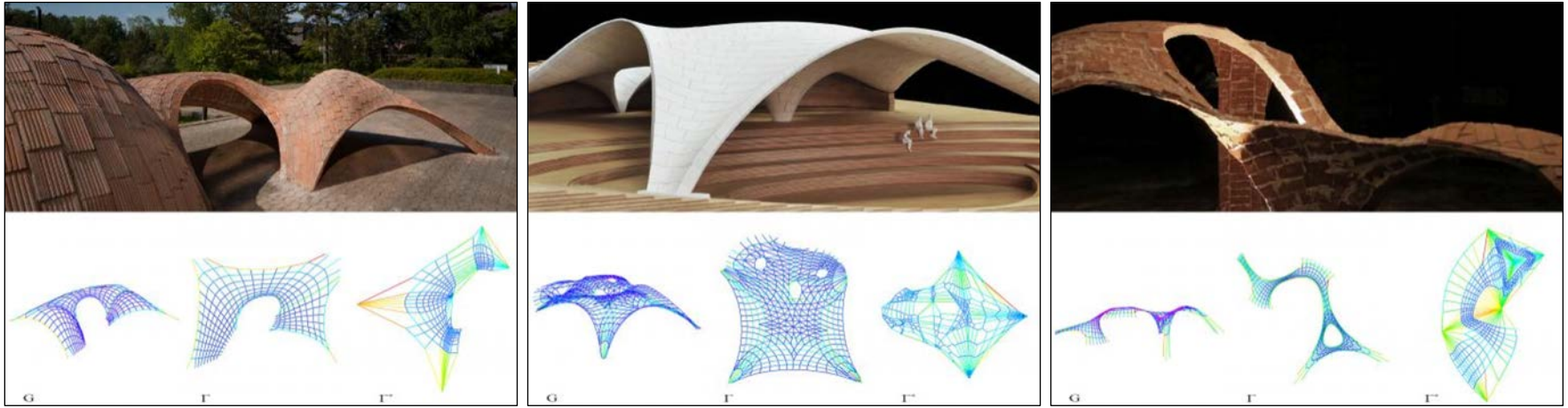




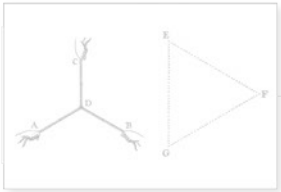
Module IV · Algebraic graph statics (automatic construction)



Module V · Thrust Network Analysis & RhinoVAULT



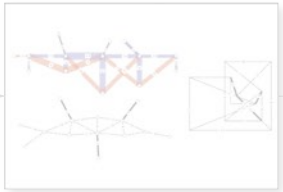
2D



Module I
Basics of Graphic Statics

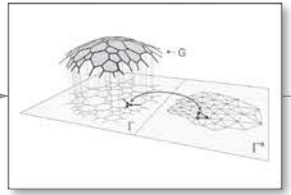
Module II
Interactive Graphic Statics I (single node)

Module III
Interactive Graphic Statics 2 (multi node)



Module IV
Algebraic Graph Statics

2.5D

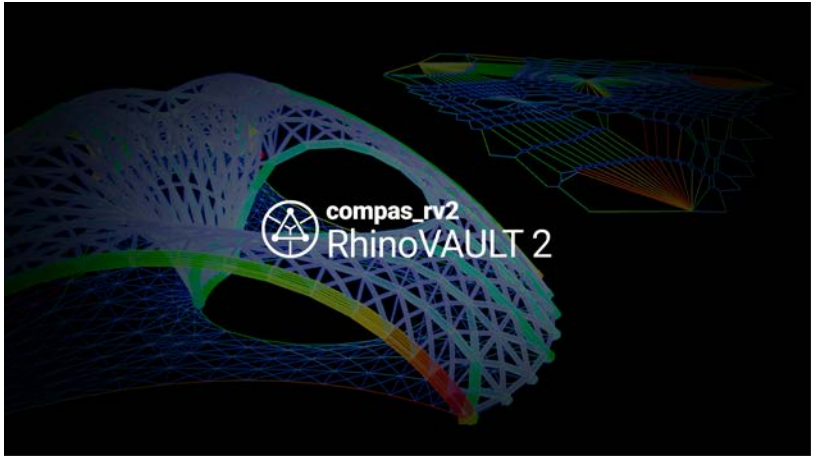


Module V
Thrust Network Analysis

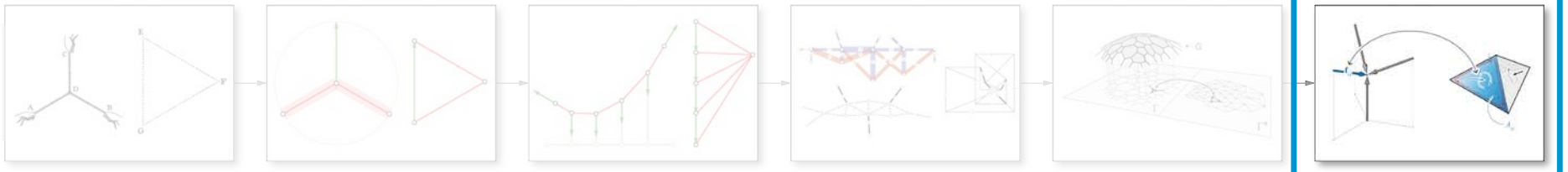
3D

Module VI
3D Graphic Statics

Module V · Thrust Network Analysis & RhinoVAULT



2D | 2.5D | 3D



Module I
Basics of Graphic Statics

Module II
Interactive Graphic Statics I (single node)

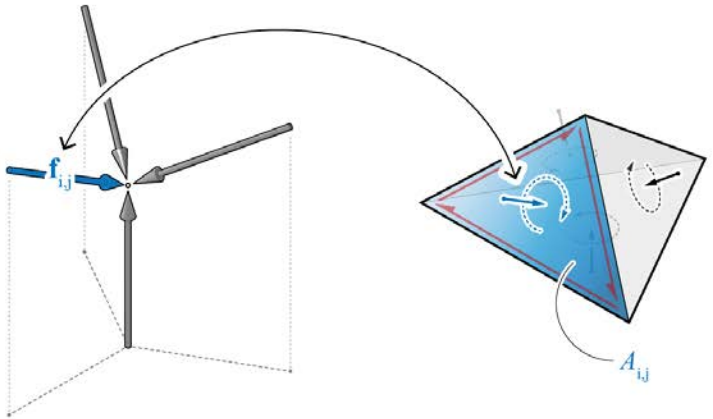
Module III
Interactive Graphic Statics 2 (multi node)

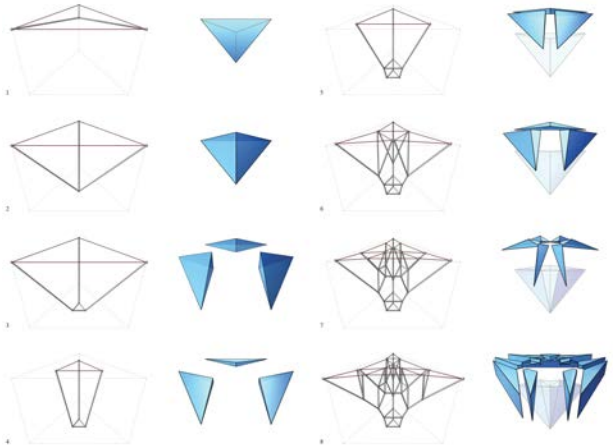
Module IV
Algebraic Graph Statics

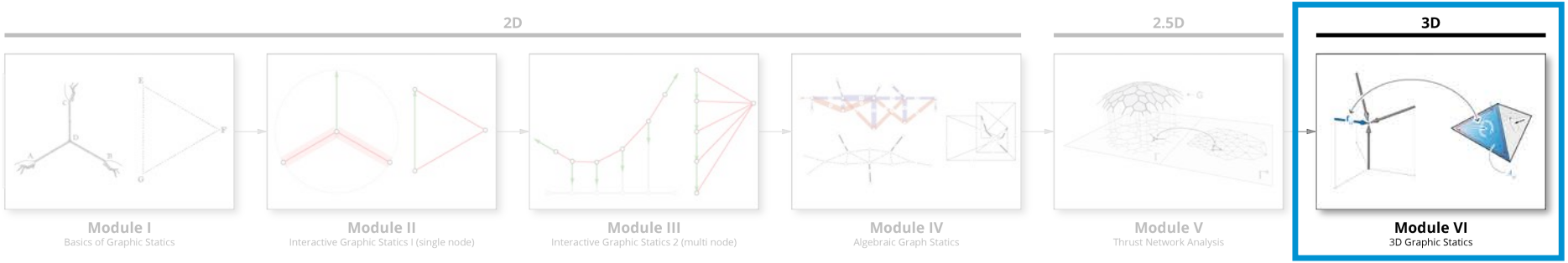
Module V
Thrust Network Analysis

Module VI
3D Graphic Statics

Module VI · 3D graphic statics

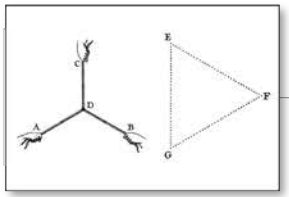




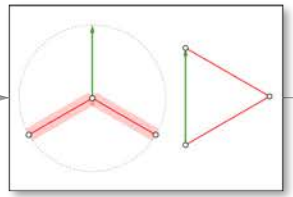


Module VI · 3D graphic statics

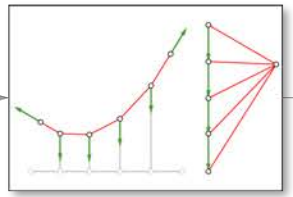
2D | 2.5D | 3D



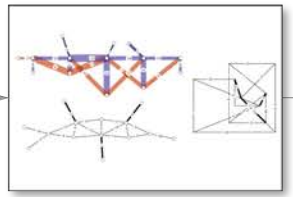
Module I
Basics of Graphic Statics



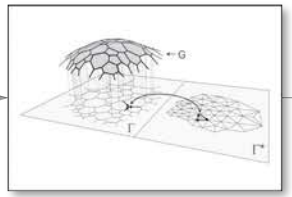
Module II
Interactive Graphic Statics I (single node)



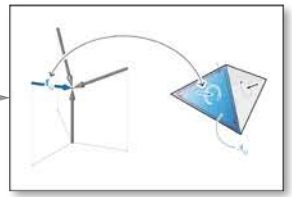
Module III
Interactive Graphic Statics 2 (multi node)



Module IV
Algebraic Graph Statics

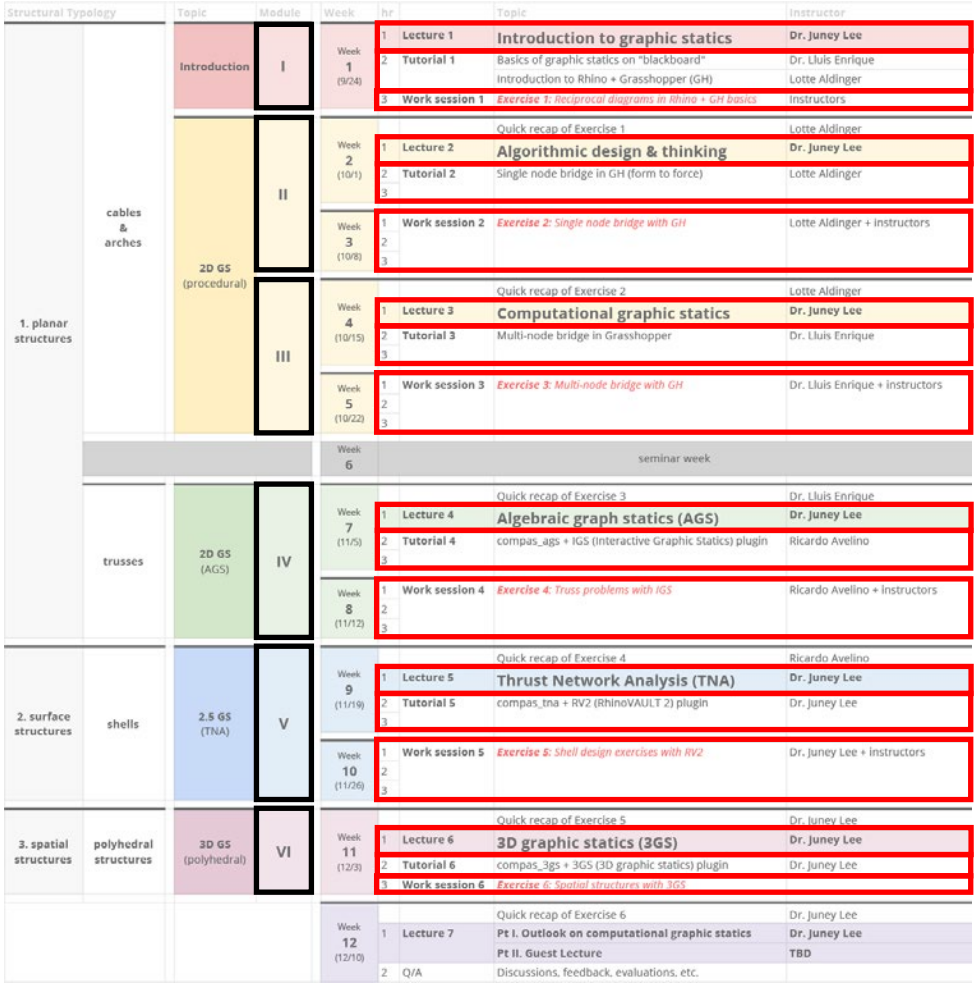


Module V
Thrust Network Analysis



Module VI
3D Graphic Statics

Rhinoceros



Structural Typology		Topic	Module	Week	hr		Topic	Instructor
1. planar structures	cables & arches	Introduction	I	Week 1 (9/24)	1	**Lecture 1**	**Introduction to graphic statics**	**Dr. Juney Lee**
					2	**Tutorial 1**	Basics of graphic statics on "blackboard"	Dr. Lluis Enrique
							Introduction to Rhino + Grasshopper (GH)	Lotte Aldinger
					3	**Work session 1**	*Exercise 1: Reciprocal diagrams in Rhino + GH basics*	Instructors
		2D GS (procedural)	II	Week 2 (10/1)			Quick recap of Exercise 1	Lotte Aldinger
					1	**Lecture 2**	**Algorithmic design & thinking**	**Dr. Juney Lee**
					2	**Tutorial 2**	Single node bridge in GH (form to force)	Lotte Aldinger
					3			
				Week 3 (10/8)	1	**Work session 2**	*Exercise 2: Single node bridge with GH*	Lotte Aldinger + instructors
					2			
					3			
			III	Week 4 (10/15)			Quick recap of Exercise 2	Lotte Aldinger
					1	**Lecture 3**	**Computational graphic statics**	**Dr. Juney Lee**
					2	**Tutorial 3**	Multi-node bridge in Grasshopper	Dr. Lluis Enrique
					3			
				Week 5 (10/22)	1	**Work session 3**	*Exercise 3: Multi-node bridge with GH*	Dr. Lluis Enrique + instructors
					2			
					3			
				Week 6	seminar week			
	trusses	2D GS (AGS)	IV	Week 7 (11/5)			Quick recap of Exercise 3	Dr. Lluis Enrique
					1	**Lecture 4**	**Algebraic graph statics (AGS)**	**Dr. Juney Lee**
					2	**Tutorial 4**	compas_ags + IGS (Interactive Graphic Statics) plugin	Ricardo Avelino
					3			
				Week 8 (11/12)	1	**Work session 4**	*Exercise 4: Truss problems with IGS*	Ricardo Avelino + instructors
					2			
					3			
2. surface structures	shells	2.5 GS (TNA)	V	Week 9 (11/19)			Quick recap of Exercise 4	Ricardo Avelino
					1	**Lecture 5**	**Thrust Network Analysis (TNA)**	**Dr. Juney Lee**
					2	**Tutorial 5**	compas_tna + RV2 (RhinoVAULT 2) plugin	Dr. Juney Lee
					3			
				Week 10 (11/26)	1	**Work session 5**	*Exercise 5: Shell design exercises with RV2*	Dr. Juney Lee + instructors
					2			
					3			
3. spatial structures	polyhedral structures	3D GS (polyhedral)	VI	Week 11 (12/3)			Quick recap of Exercise 5	Dr. Juney Lee
					1	**Lecture 6**	**3D graphic statics (3GS)**	**Dr. Juney Lee**
					2	**Tutorial 6**	compas_3gs + 3GS (3D graphic statics) plugin	Dr. Juney Lee
					3	**Work session 6**	*Exercise 6: Spatial structures with 3GS*	
				Week 12 (12/10)			Quick recap of Exercise 6	Dr. Juney Lee
					1	**Lecture 7**	**Pt I. Outlook on computational graphic statics**	**Dr. Juney Lee**
							Pt II. Guest Lecture	**TBD**
					2	Q/A	Discussions, feedback, evaluations, etc.	

Week 1 Friday, September 24th

Hour 1	**9:45 – 10:30**	· Welcome & introduction · **Lecture 1: Introduction to graphic statics** · Basics of graphic statics
	10:30 – 10:45	· Mandatory 15 min break
Hour 2	**10:45 – 11:30**	· **Tutorial 1: Introduction to Rhino & Grasshopper**
	11:30 – 11:45	· Mandatory 15 min break
Hour 3	**11:45 – 12:30**	· Introduction of exercise 1 · **Work session 1**

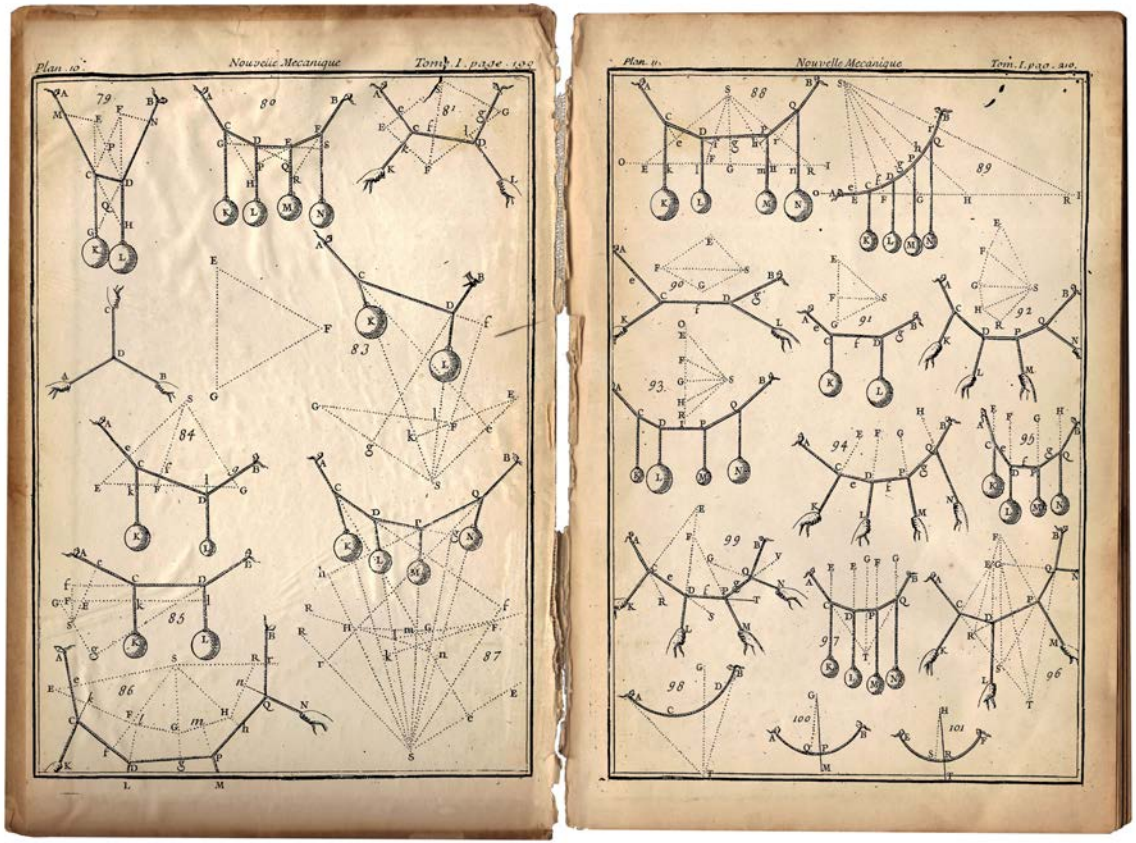
063-0605-00L : Computational Structural Design 1

Computational Graphic Statics

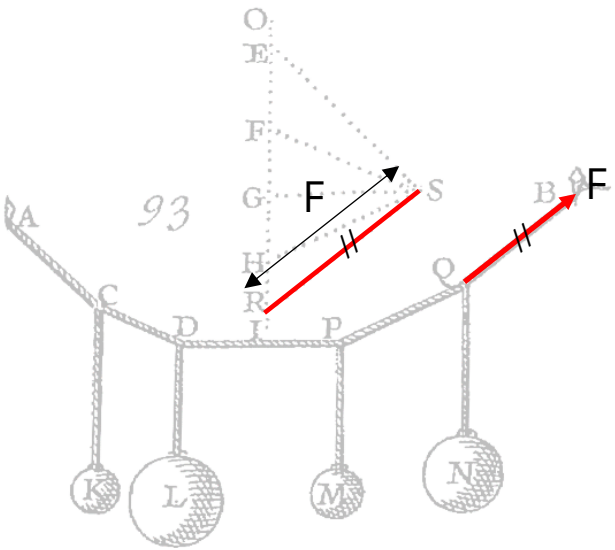
Lecture 1
Introduction to Graphic Statics

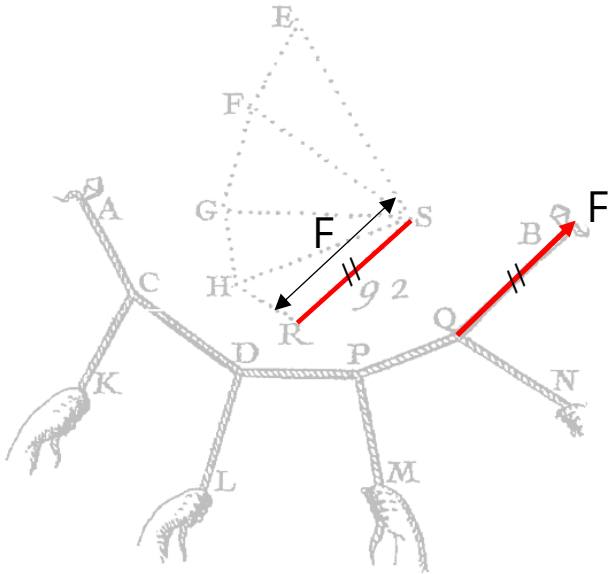
Friday, September 24th, 2021

Dr. Juney Lee
Dr. Lluis Enrique



"Nouvelle mécanique ou Statique" | Varignon (1725)



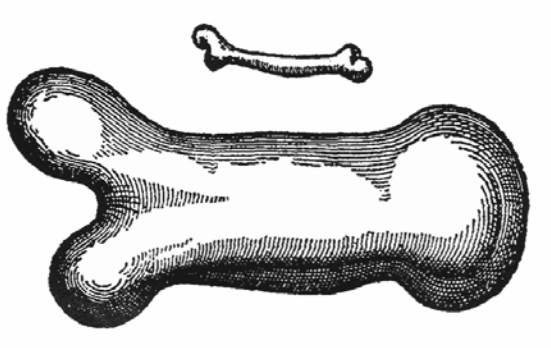


Varignon (1725)

Stress

↓

Material failure

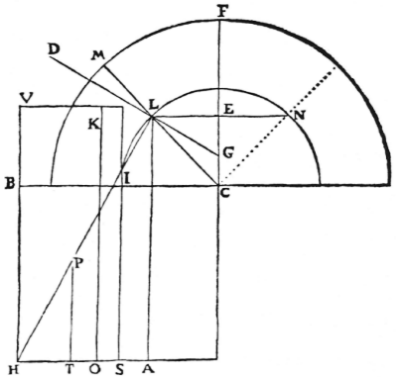


Galilei (1638)

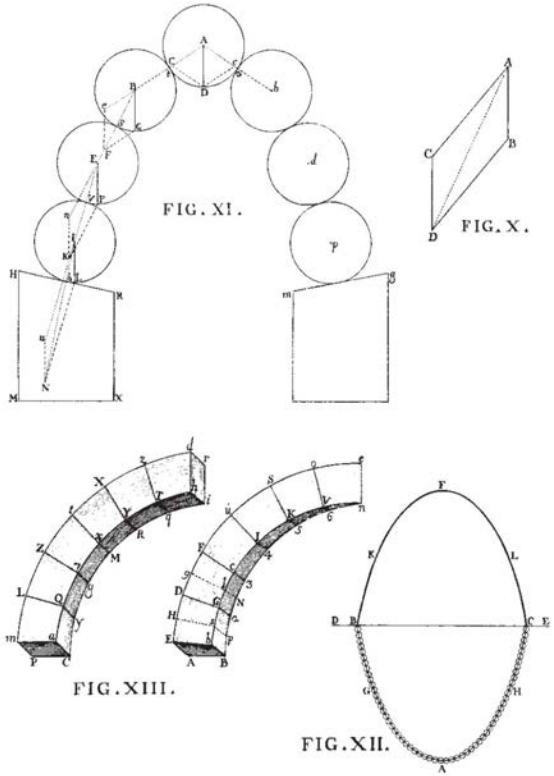
Stability

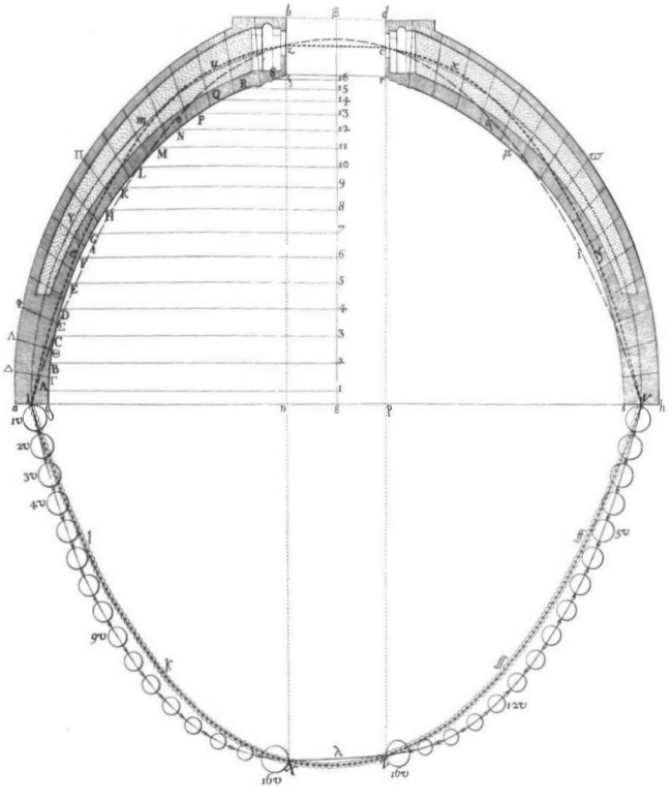
↓

Geometry

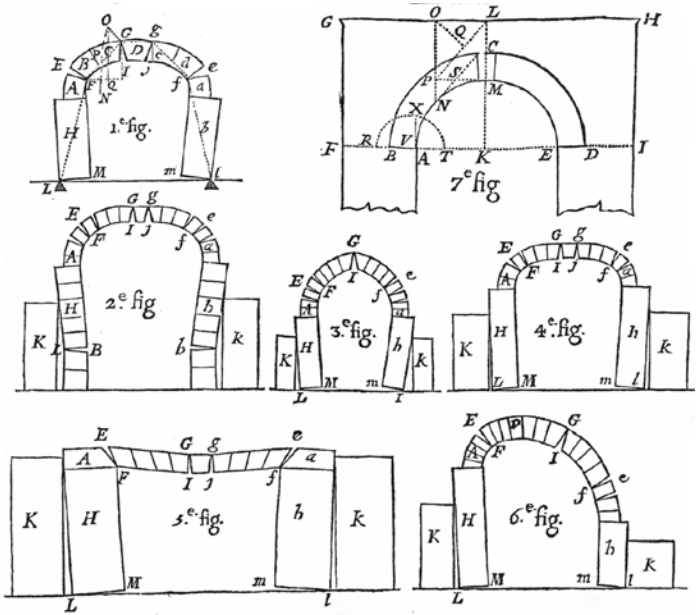


de Lahire (1695)

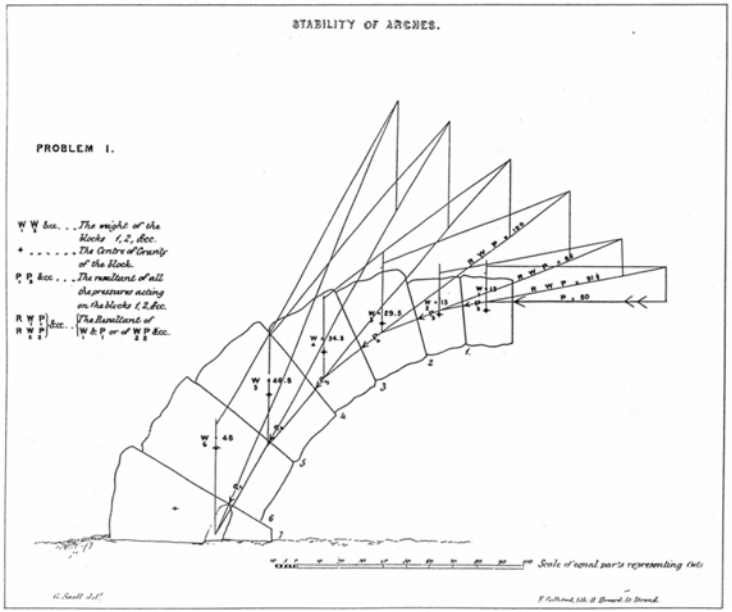


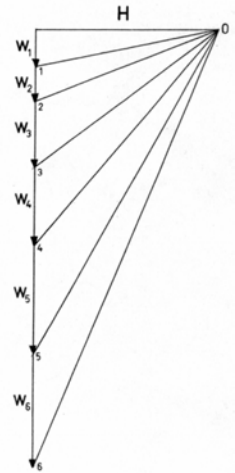


Poleni (1748)

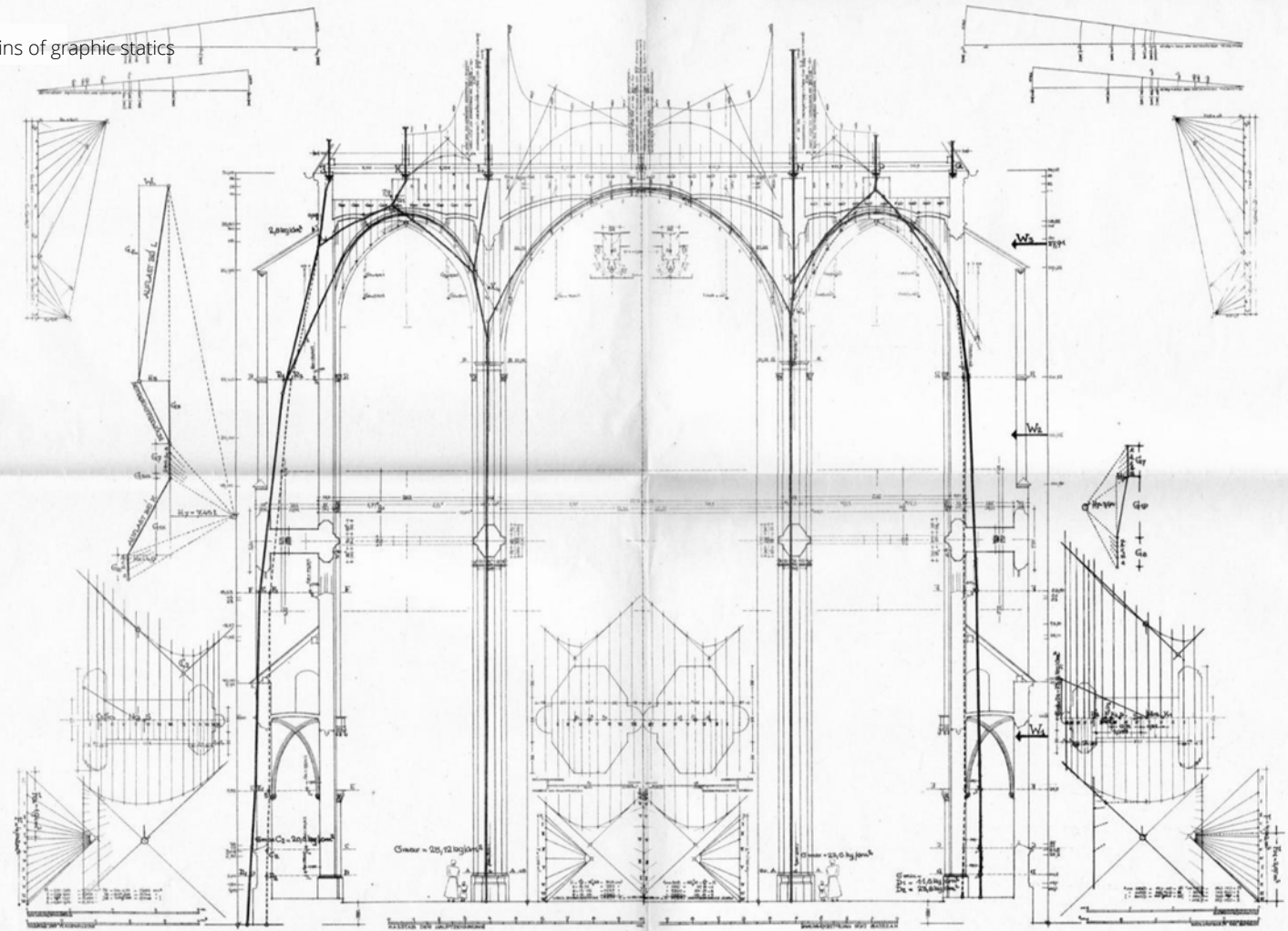


Danyzy (1732)

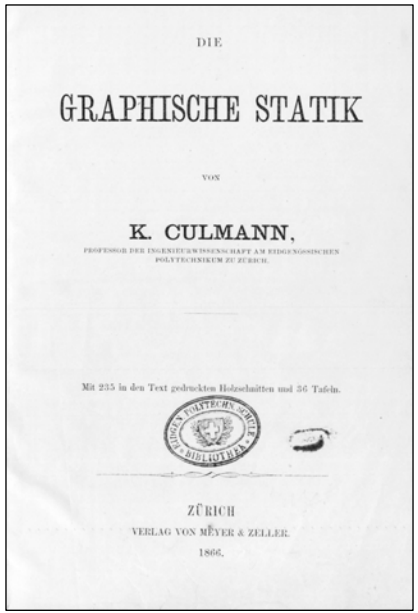




Snell (1846)



Zorn (1936)



DIE

GRAPHISCHE STATIK

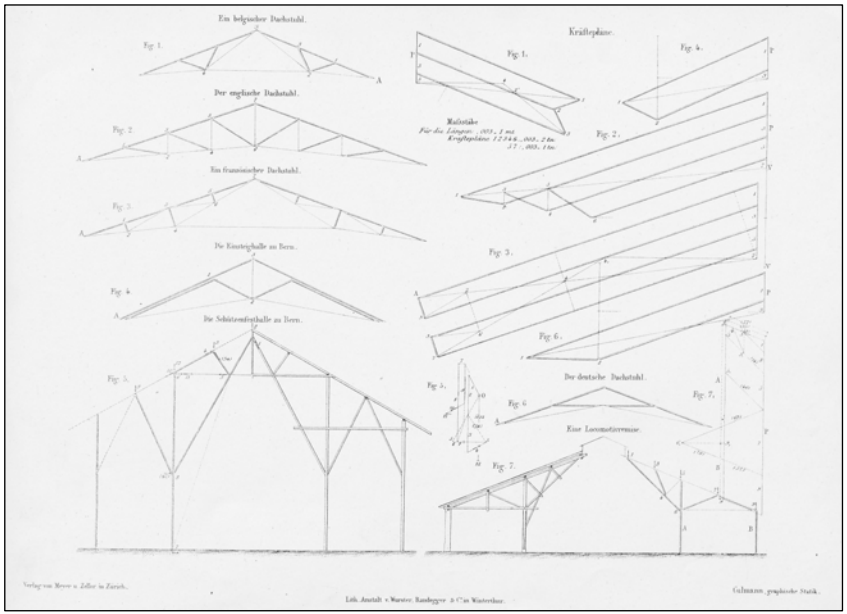
VON

K. CULMANN,

PROFESSOR DER INGENIEURWISSENSCHAFT AM EIDGENÖSSISCHEN POLYTECHNIKUM ZU ZÜRICH.

Mit 235 in den Text gedruckten Holzschnitten und 56 Tafeln.

ZÜRICH
VERLAG VON MEYER & ZELLER.
1866.



Graphische Statik" | Culmann (1866)

the upper extremity of the segment 1 meets the upper extremity of the segment 2 ; and the straight line 18 through the point (16, 1), which is both the lower extremity of the segment 16 and that of the segment 1.

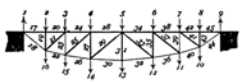


Fig. 8a.

Pass on to the joint (2, 17, 19, 20). Draw 19 through the point (17, 18), and 20 through the point (2, 3), the lower end of 2 and upper extremity of 3 ; and we obtain the polygon 2, 17, 19, 20, which is a rectangle.

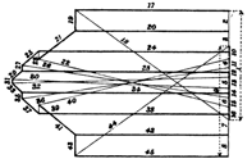


Fig. 8b.

Construct the polygon corresponding to the joint (16, 18, 19, 21, 22). For this purpose draw 21 through the point (19, 20), and 22 through the point (15, 16) ; we thus obtain a crossed pentagon. Continue to deal in the same manner with each of the points of application of the forces 3, 15, 4, 14, 13, 5, 12, 6, 11, 7, 10, 9, taken in succession.

Since the diagram *a*, which represents the skeleton of the structure and all the external forces, has for its axis of symmetry the vertical which passes through the centre of the figure, the diagram *b* has for its axis of symmetry the median horizontal line. For example, the triangle 9, 45, 44 is sym-

metrical to the triangle 1, 17, 18 ; the rectangle 8, 45, 43, 42 to the rectangle 2, 17, 19, 20: and so on.

All the upper bars are in compression, and all the lower ones are in tension.

The diagonals and contra-diagonals are all in compression ; finally two of the verticals 23, 39 are in tension, and all the rest in compression.

44. Figure 9*a** represents one half of a locomotive shed. The external forces are the weights 1, 2, 3, 4, 5 applied at

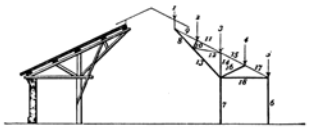


Fig. 9a.

the upper joints of the frame, and the reactions 6 and 7 of the wall and column. Again, all the external forces are parallel, and consequently the polygon of forces reduces, in diagram *b*, to one straight line. The force 6 (taken in the opposite sense to that in which it really acts) is equal to a certain part of the weight 5 ; by adding the difference to the other weights we get the magnitude of the force 7.

In the diagram *b* the direction of the lines 8 and 13 coincide ; the first is a part of the second. Here then we have for the polygon corresponding to the joint (8, 10, 12, 13) one of those degenerate forms about which we spoke in Art. 33 ; the polygon is in fact a quadrilateral 8, 10, 12, 13, having three of its vertices (13, 8), (8, 10), (12, 13) in one straight line.

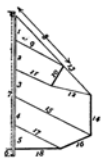


Fig. 9b.

The polygon 5, 17, 18, 6, corresponding to the point where

* This example is taken from Pl. xix. of the atlas of *Graphische Statik* of CULMANN, 1st edition. As previously stated, the two diagrams are not rigorously reciprocal.

the roof is supported by the wall, presents an analogous degenerate form, since the vertices (6, 5), (upper point of the segment (6), (5, 17), and (18, 6) all lie in the same straight line.

The lower bars 8, 13, 18 are in compression, as well as the diagonals 10, 14, 16, the column 7 and the wall 6 ; while the upper pieces 9, 11, 15, 17 and the diagonal 12 are in tension.

45. Diagram *a* of Fig. 10 represents a truss at the upper joints of which are applied the oblique forces 1, 2, ..., 7, which

Fig. 10a.

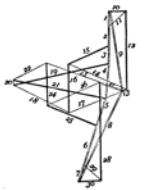


Fig. 10b.

may be considered as the resultants of the dead-loads and wind pressure ; the forces 8, 9 represent the reactions at the supports.

The polygon of external forces is drawn in diagram *b* with double lines.

We construct successively the triangle 1, 10, 11, the quadrilateral 9, 10, 12, 13, the pentagon 2, 11, 12, 14, 15, the quadrilateral 13, 14, 16, 17, the crossed pentagon 3, 15, 16, 18, 19 ; the crossed quadrilateral 4, 19, 20, 21, the pentagon 17, 18, 20, 22, 23, and so on.

The upper bars 15, 19, 21, 25 are in compression, as well as the lower bars 10, 13, 30, and the verticals 12, 16, 24, 28 ; whilst all the remaining bars of the structure are in tension.

46. The diagram *a* of Fig. 11 represents a suspension bridge, loaded at each of its upper joints with weights 1, 2, ..., 8, and at each of its lower joints with weights 10, 11, 21, ..., 16 ; the weights are kept in equilibrium by the two

oblique reactions 9, 17 at the two extreme points of the structure*.

The polygon of external forces has its first eight sides in succession along the same vertical straight line, and its seven

Fig. 11a.

last sides situated in another vertical straight line. The oblique sides 9 and 17 intersect, so that the polygon is a crossed one. We construct successively the polygons 1, 17, 19, 18 ; 16, 19, 20, 21 ; 2, 18, 20, 22, 23 ; 15, 21, 22, 24, 25 ; 3, 23, 24, 26, 27 ; and so on ; most of which are crossed.

Diagram *b* shows that the upper bars are all in tension, and that the tension decreases from the ends towards the

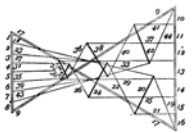
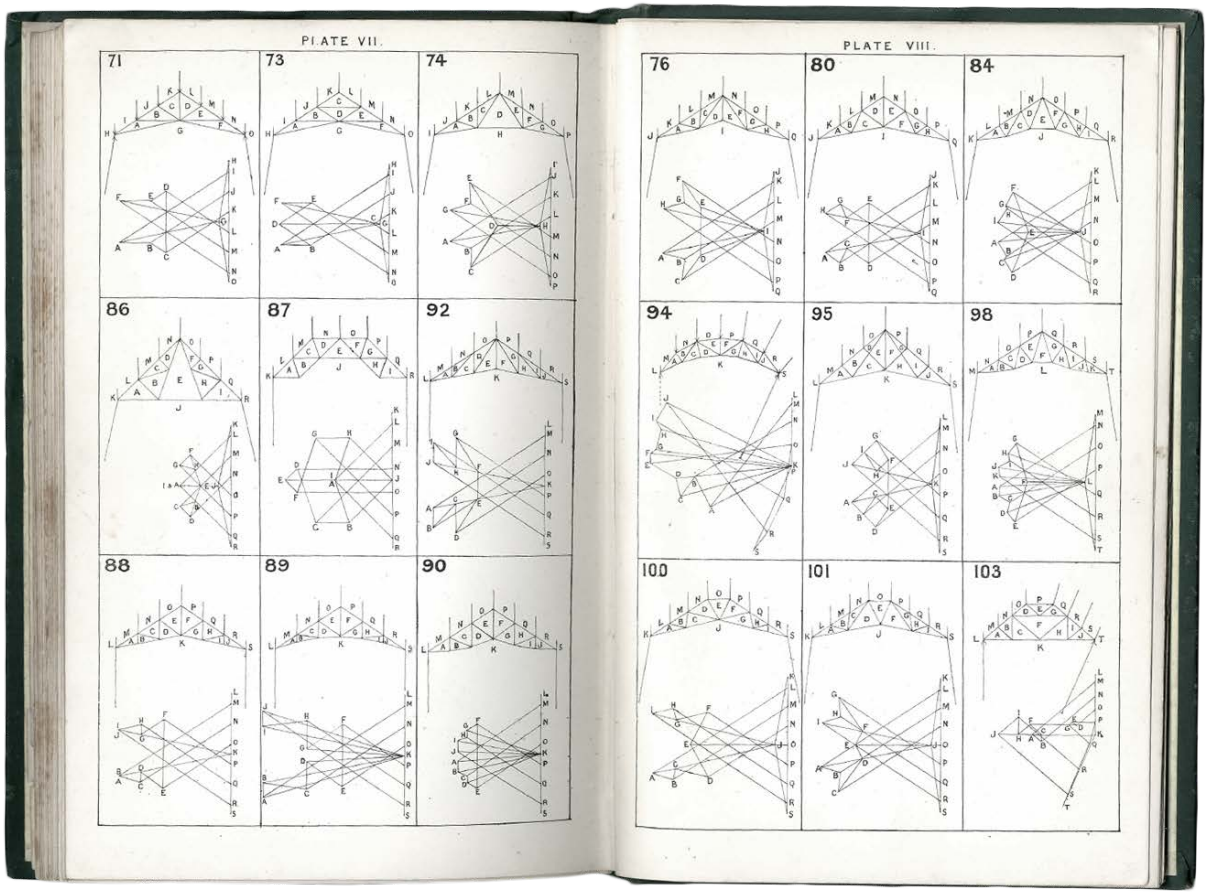


Fig. 11b.

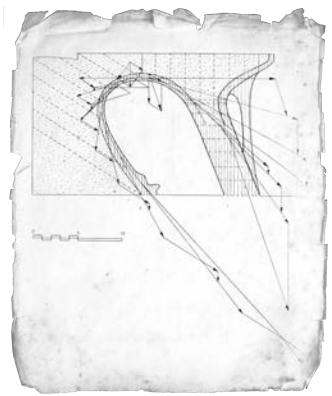
middle of the structure ; the bars of the lower boom are also all in tension, but in them the tension decreases from the middle towards the ends.

The extreme diagonals and contra-diagonals are in tension ; in the portion situated to the left of the axis of symmetry, the diagonals or braces are alternately in tension and compression ; similarly they are on the right but in the reverse order. Considering separately the ties and struts, we see that the internal

* This example is analogous to one of those studied by MAXWELL in his memoir of 1870.

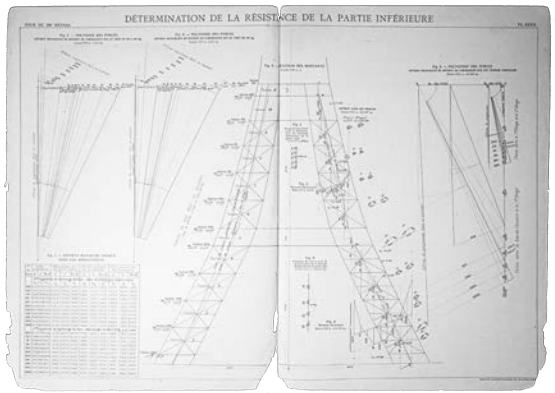


Economics of Construction in Relation to Framed Structures | Bow (1873)



Park Güell | Gaudi (1914)

Rubio 1913, Tarrago 1991



Eiffel Tower | Gustave Eiffel (1889)

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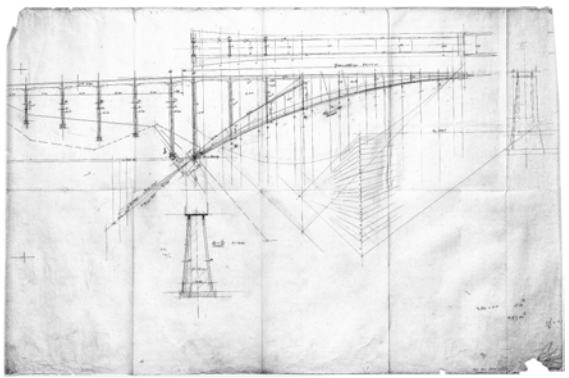
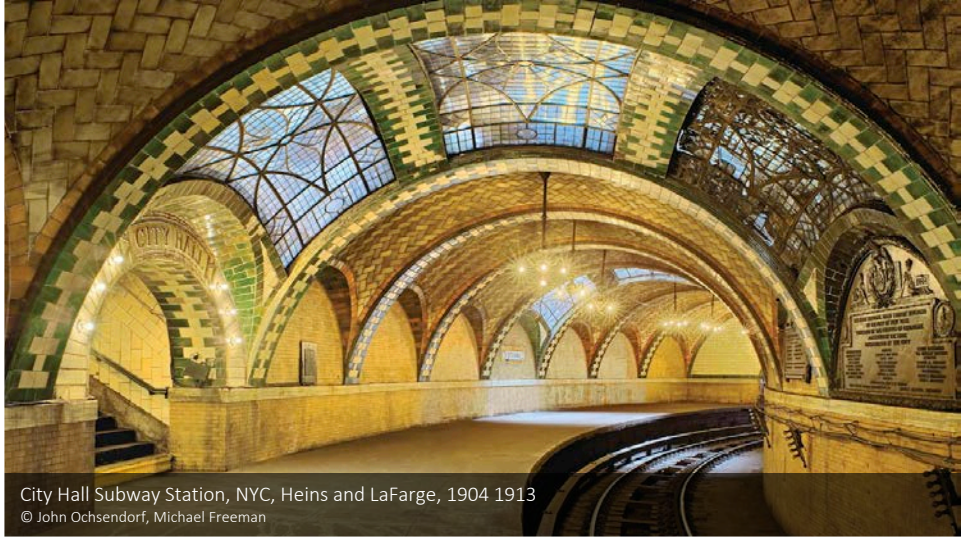


Salginatobel Bridge | Robert Maillart (1914)

Robert Maillart Archives

Oyster Bar, Grand Central Terminal, Warren and Wetmore, NYC, 1912-1913
© John Ochsendorf, Michael Freeman



City Hall Subway Station, NYC, Heins and LaFarge, 1904 1913
© John Ochsendorf, Michael Freeman

Queensborough Bridge Market, NYC, Palmer and Hornbostel, 1917 1913
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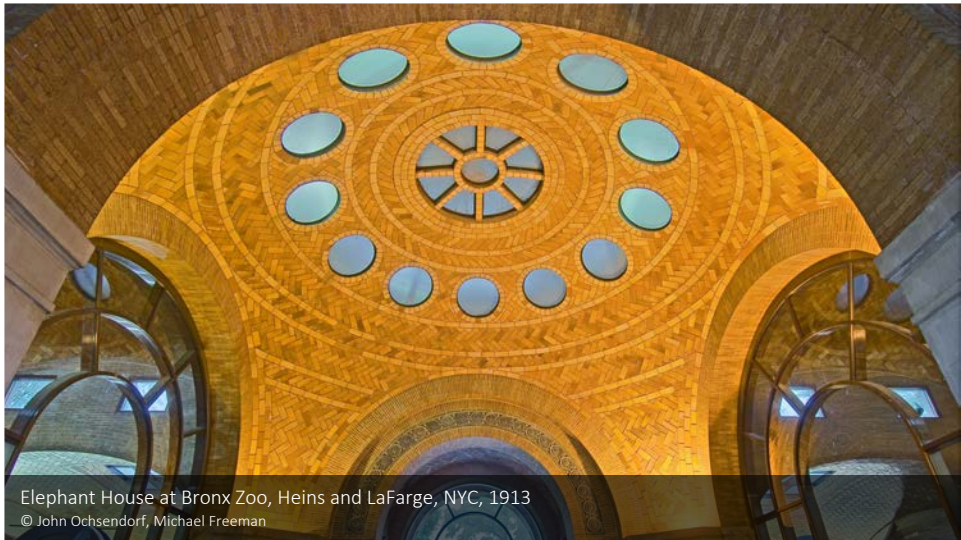
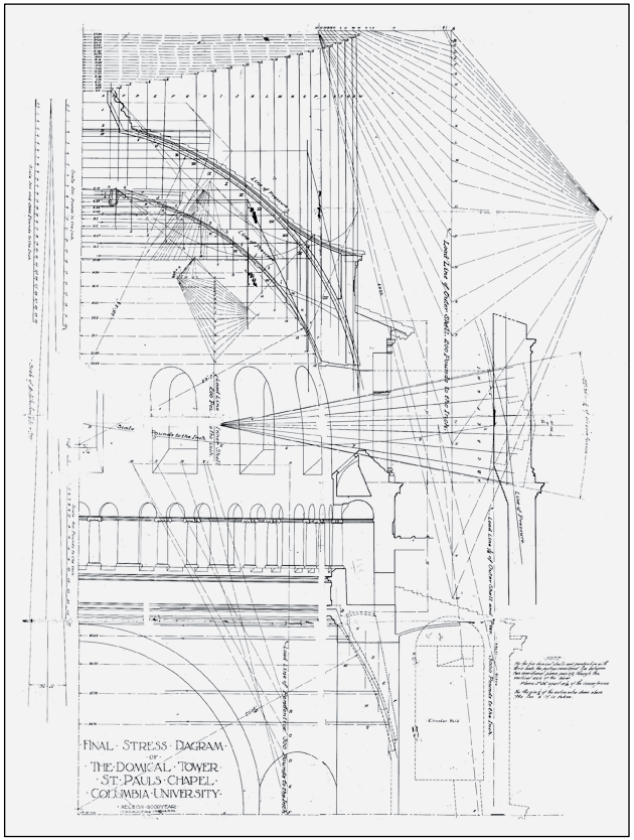


Elephant House at Bronx Zoo, Heins and LaFarge, NYC, 1913
© John Ochsendorf, Michael Freeman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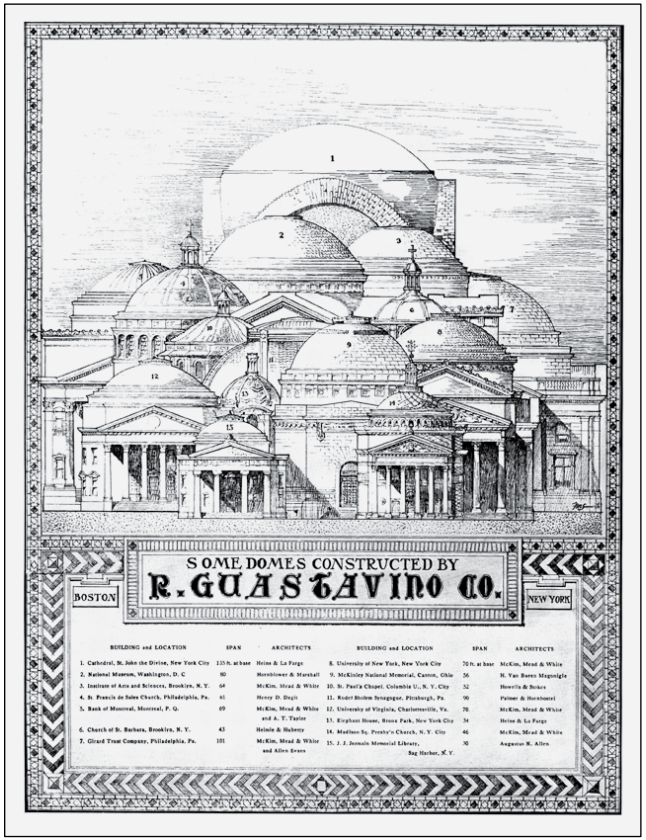
· COLUMBIA · UNIVERSITY ·


SOME DOMES CONSTRUCTED BY
R. GUASTAVINO CO.
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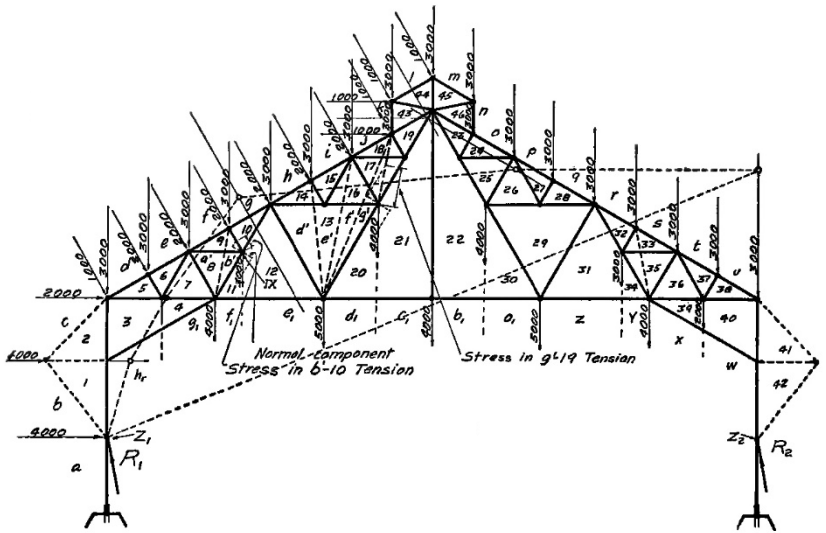
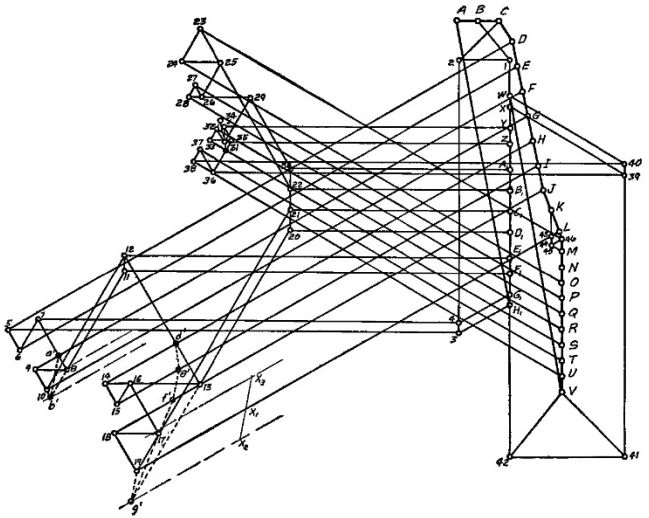
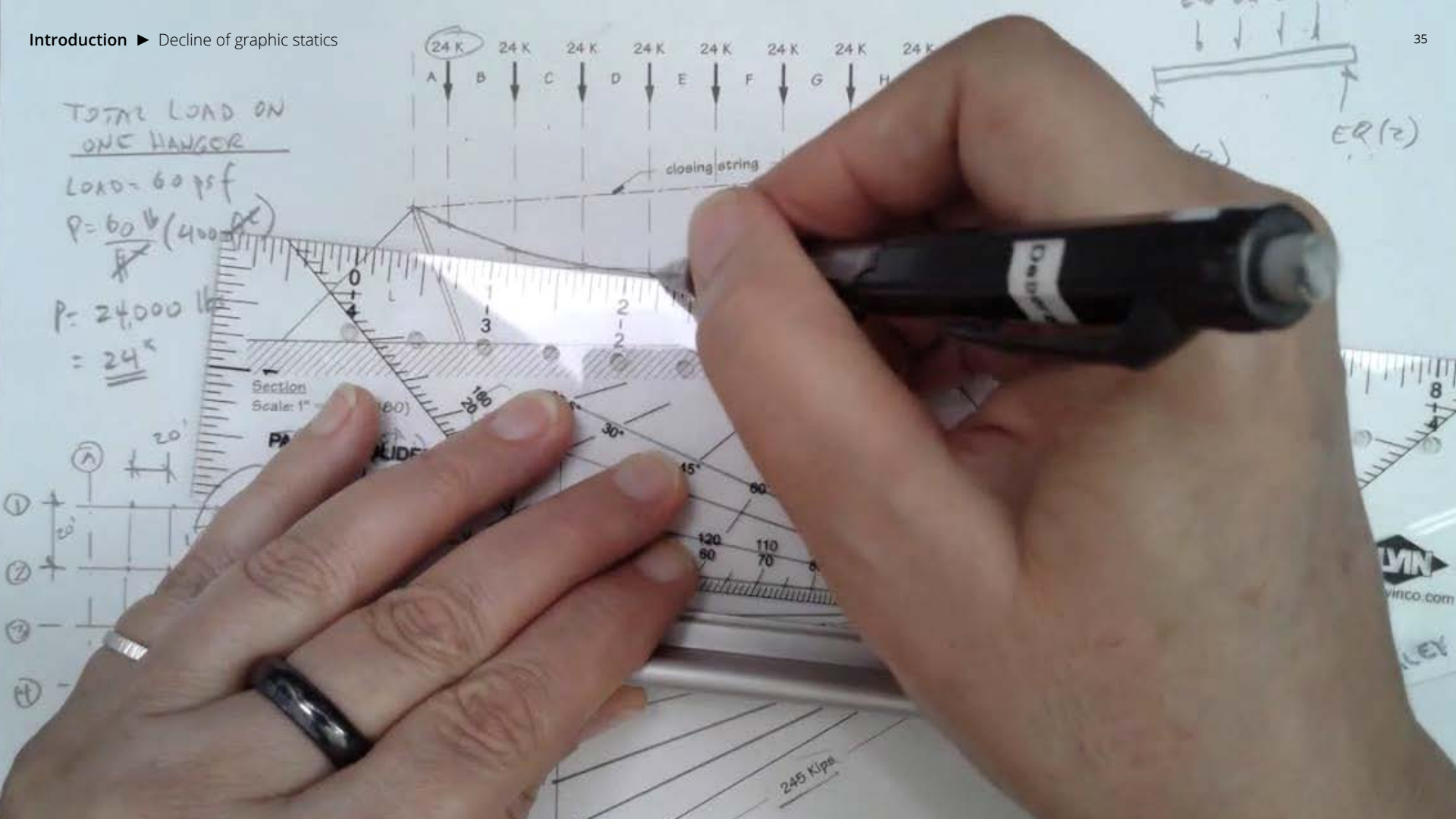
NEW YORK
BUILDING and LOCATION
SPAN
ARCHITECTS
1. Cathedral, St. John the Divine, New York City 135 ft. at base Heins & La Farge
2. National Museum, Washington, D. C 80 Hornblower & Marshall
3. Institute of Arts and Sciences, Brooklyn, N. Y. 64 McKim, Mead & White
4. St. Francis de Sales Church, Philadelphia, Pa. 45 Henry D. Dagit
5. Bank of Montreal, Montreal, P. Q. 69 McKim, Mead & White and A. T. Taylor
6. Church of St. Barbara, Brooklyn, N. Y. 43 Heinle & Huberty
7. Girard Trust Company, Philadelphia, Pa. 101 McKim, Mead & White and Allen Evans
8. University of New York, New York City 70 ft. at base McKim, Mead & White
9. McKinley National Memorial, Canton, Ohio 56 H. Van Buren Magonigle
10. St. Paul's Chapel, Columbia U., N. Y. City 52 Howells & Stokes
11. Rodef Sholom Synagogue, Pittsburgh, Pa. 90 Palmer & Hornbostel
12. University of Virginia, Charlottesville, Va. 70 McKim, Mead & White
13. Elephant House, Bronx Park, New York City 34 Heins & La Farge
14. Madison Sq. Presby'n Church, N. Y. City 46 McKim, Mead & White
15. J. J. Jennals Memorial Library, Sag Harbor, N. Y. 30 Augustus N. Allen

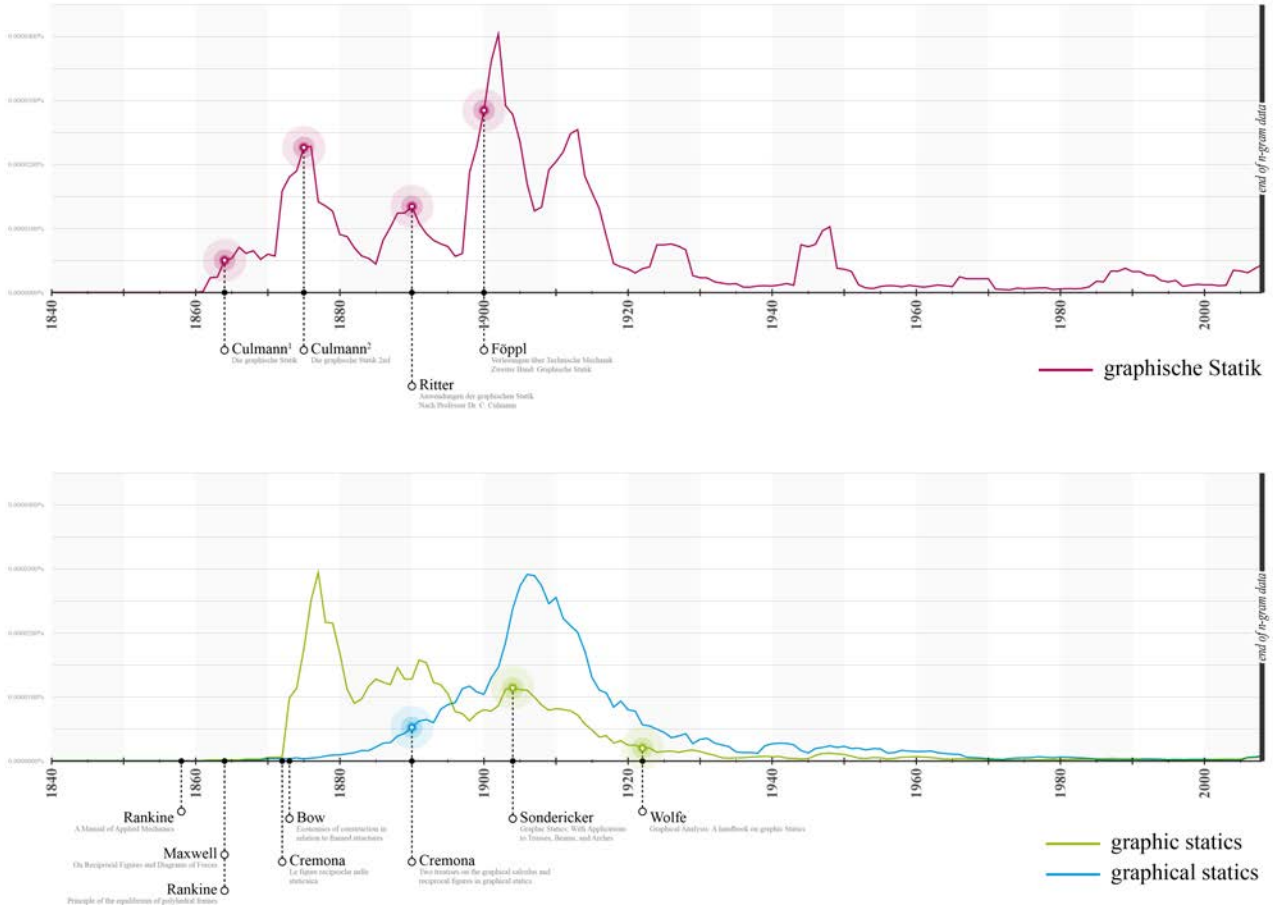


Form Diagram

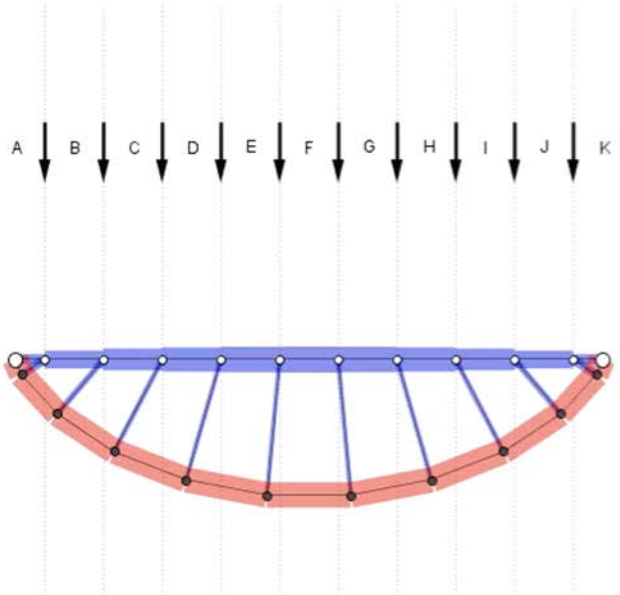


Force Diagram


24 K
A
B
C
D
E
F
G
H
TOTAL LOAD ON ONE HANGER
LOAD = 60 psf
P = 24,000 lb
= 24 K
closing string
Section
245 Kips

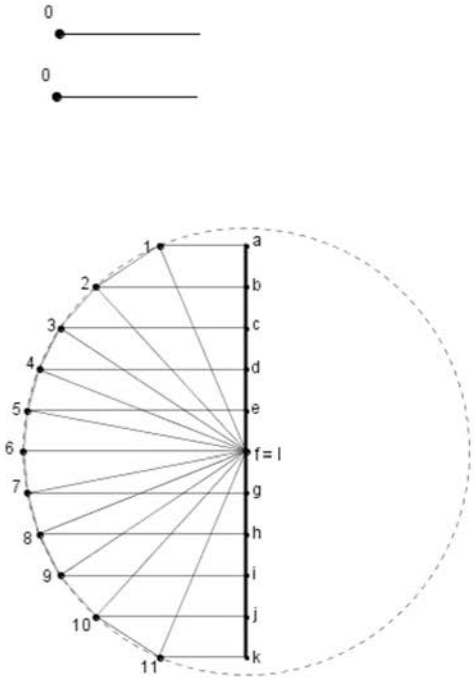


Ngrams for "graphische Statik," "graphic statics," and "graphical statics" | from PhD dissertation by Lee (2018)



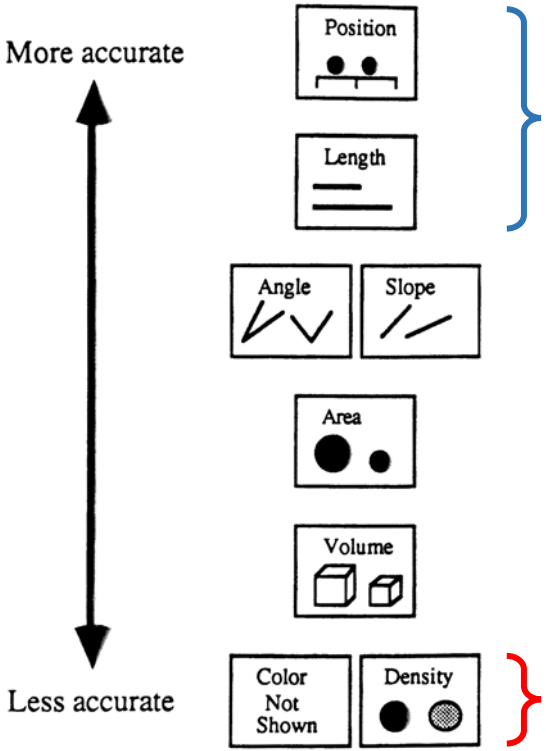
Form Diagram

Geometry of the Truss Structure

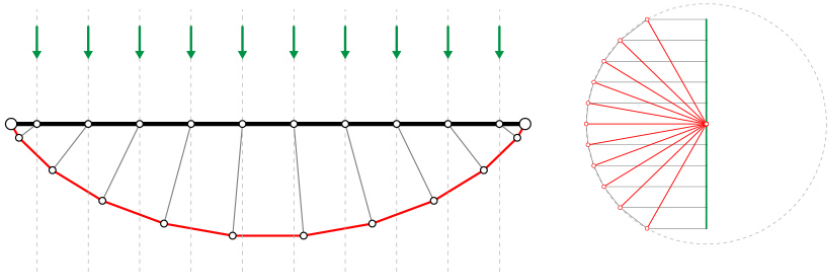


Force Diagram

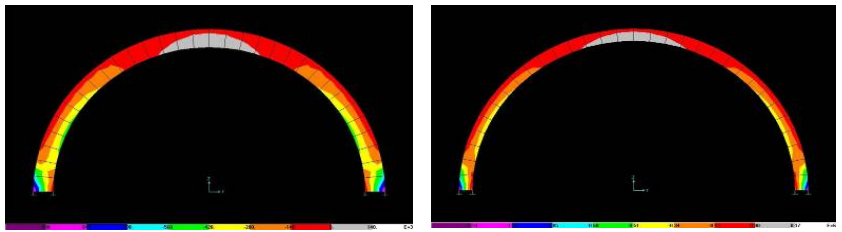
Equilibrium of Internal Forces



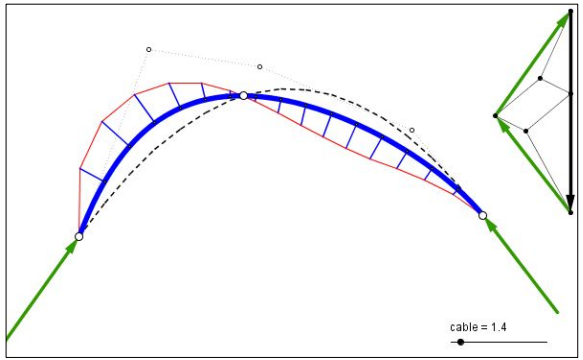
2D graphic statics



FE analysis



"Automating the Design of Graphical Presentation of Relational Information"
Mackinlay (1986)



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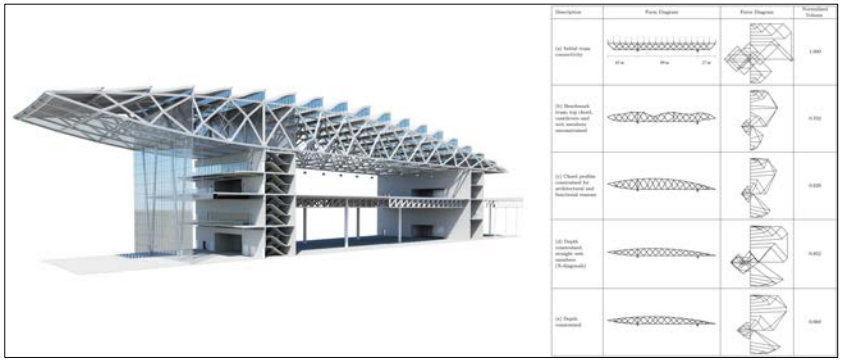
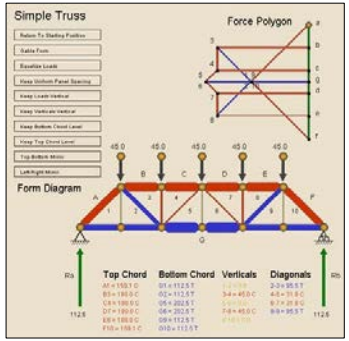
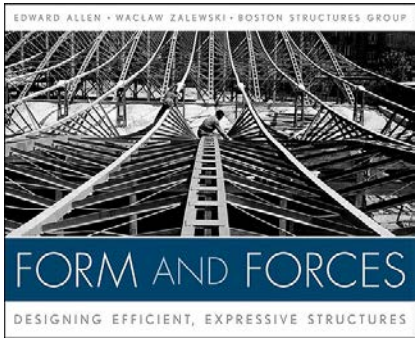
Van Mele et al. (2009-)



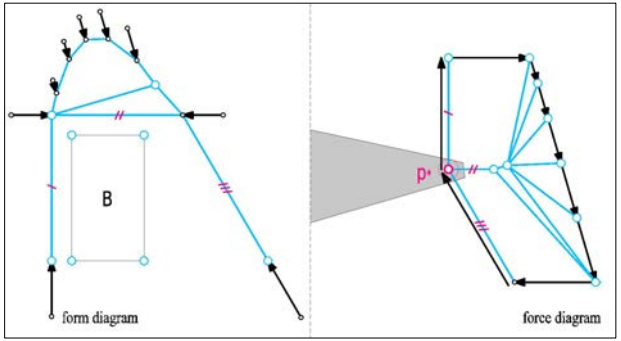
Structural Optimization using Graphic Statics
Beghini, et al. & SOM (2013)



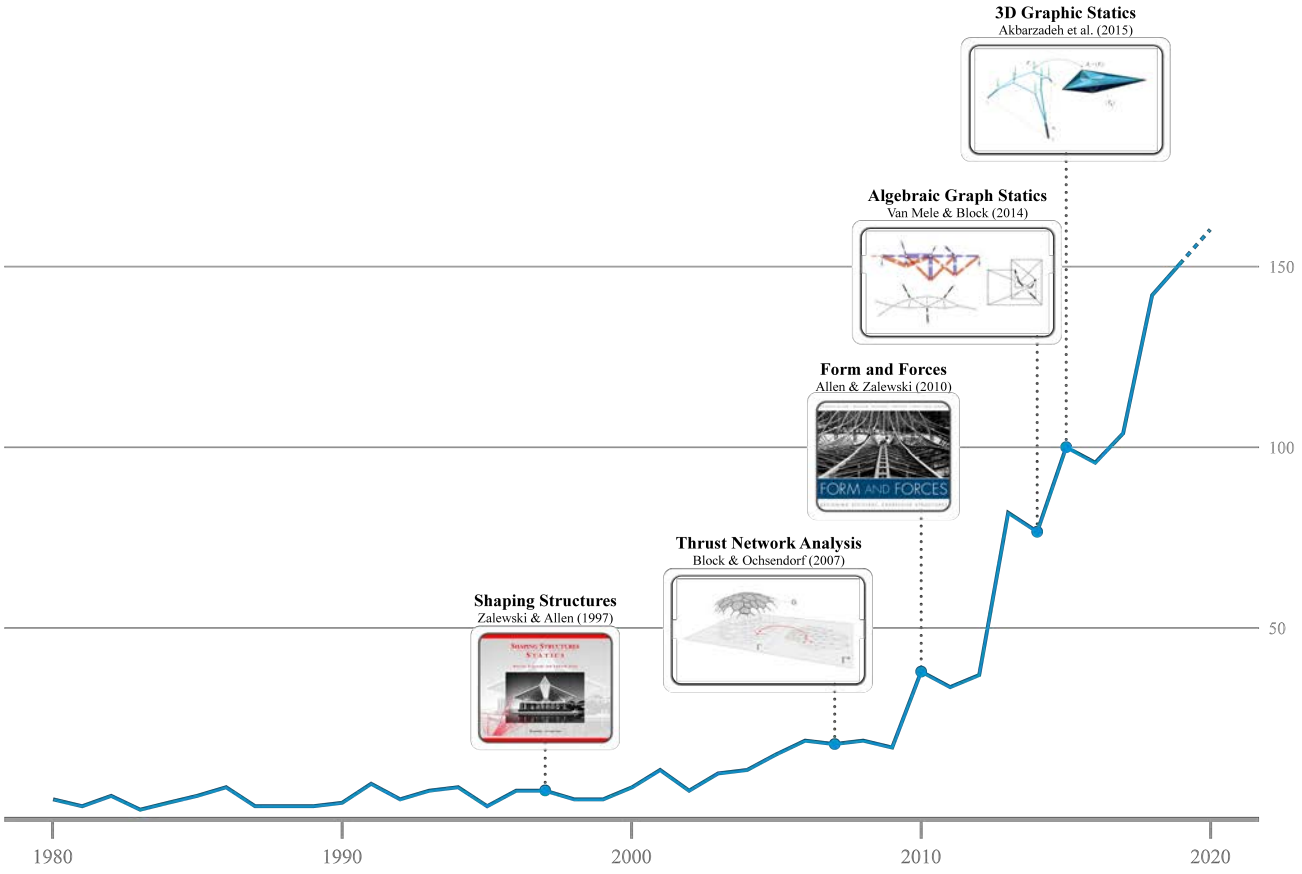
Active Statics
Greenwold & Allen (2003)



Form and Forces
Allen & Zalewski (2009)



Constraint-based Graphic Statics
Fivet & Zastavni (2013)



Timeline of graphic statics publications (early 2018) | from PhD dissertation by Lee (2018)


Campus Info

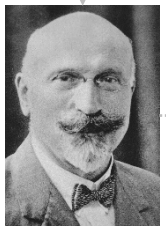

PROFESSOR DR
CARL CULMANN
VON 1855 BIS 1881
VORSTAND DER
INGENIEURSCHULE
DES EIDGENÖSSISCHEN
POLYTECHNIKUMS

Karl Culmann

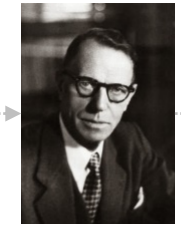
- Founder of graphic statics: “Die graphische Statik” (1864-1866)
- First Professor of Civil Engineering at the ETH Zurich (1855-1883)
- Director of the Polytechnic (1872-1875)

Karl Wilhelm Ritter (ETHZ diploma, 1868)

- Professor of graphic statics and bridge construction (appointed in 1882)
- Director of the Polytechnic (1887-1891)
- Extended applications of Culmann’s graphic statics:
  “Anwendungen der graphischen Statik nach Professor Dr. Culmann” (1888-1906)



Robert Maillart
(ETH diploma, 1894)



Othmar Ammann
(ETH diploma, 1902)

Pierre Lardy
(ETH diploma, 1928)

Heinz Isler
(ETH diploma, 1950)

Christian Menn
(ETH diploma, 1950)

Joseph Schwartz
(ETH professor, 2008-)

Philippe Block
(ETH professor, 2009-)

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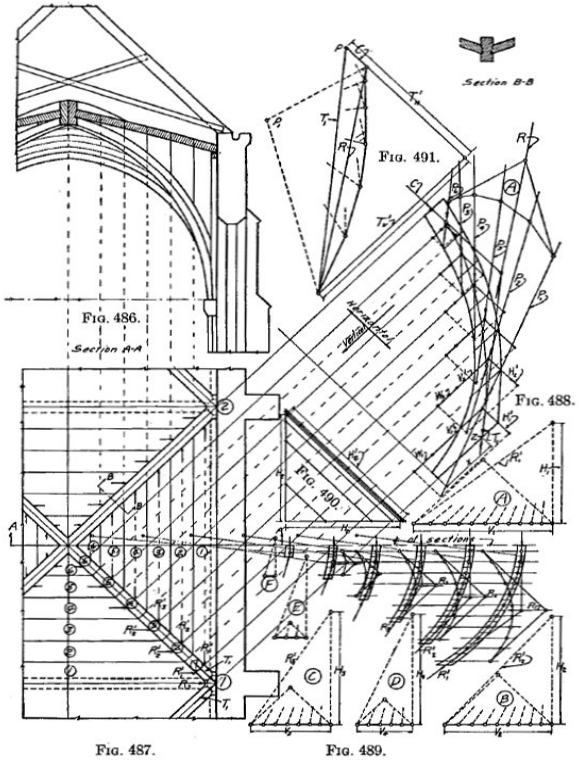
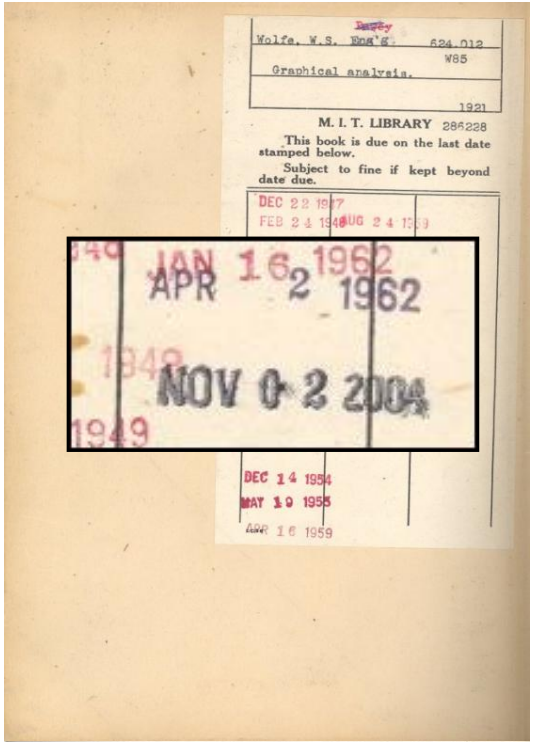
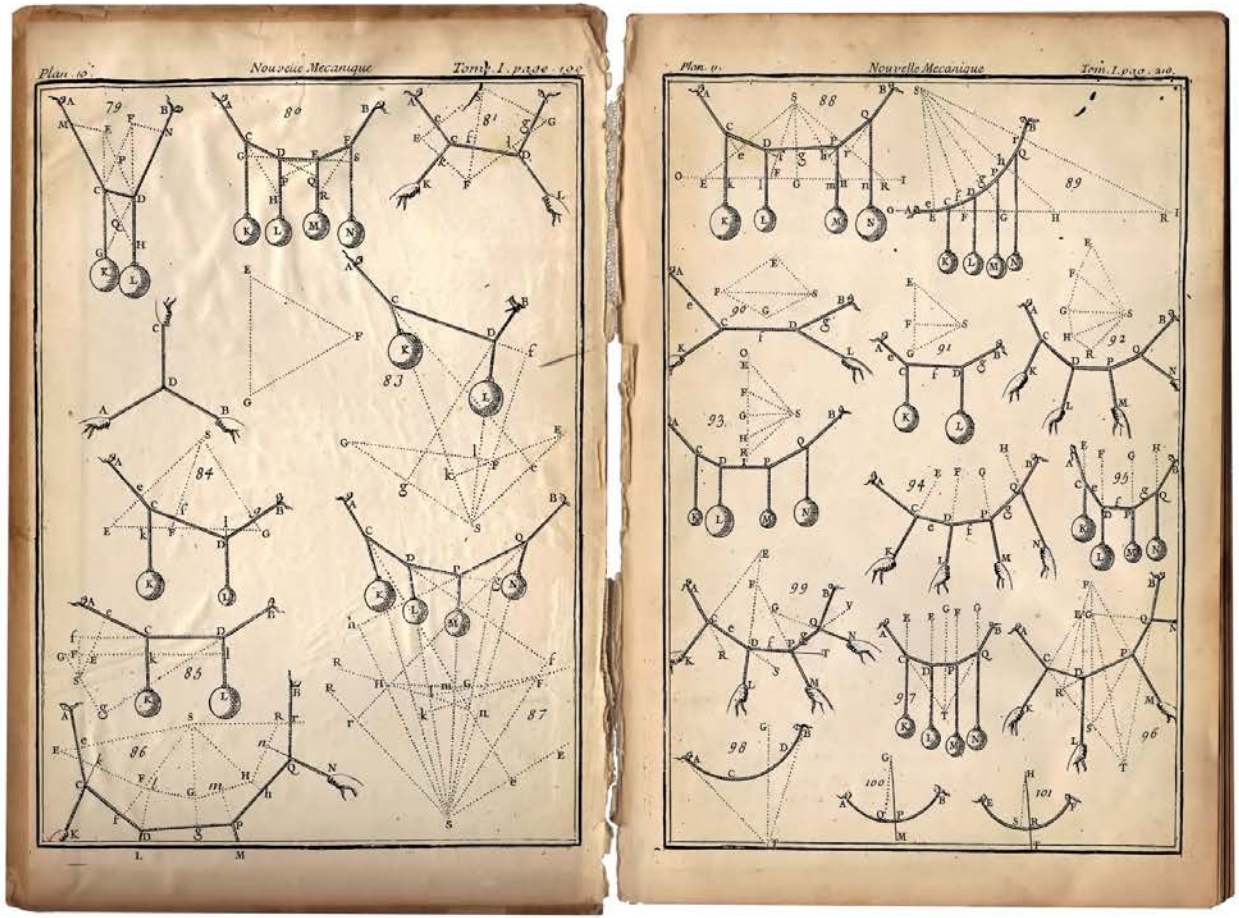




"Graphical Analysis" | Wolfe (1921)


Plan. 10.
Nouvelle Mecanique
Tom. I. page. 102
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Plan. 9.
Nouvelle Mecanique
Tom. I. page. 210
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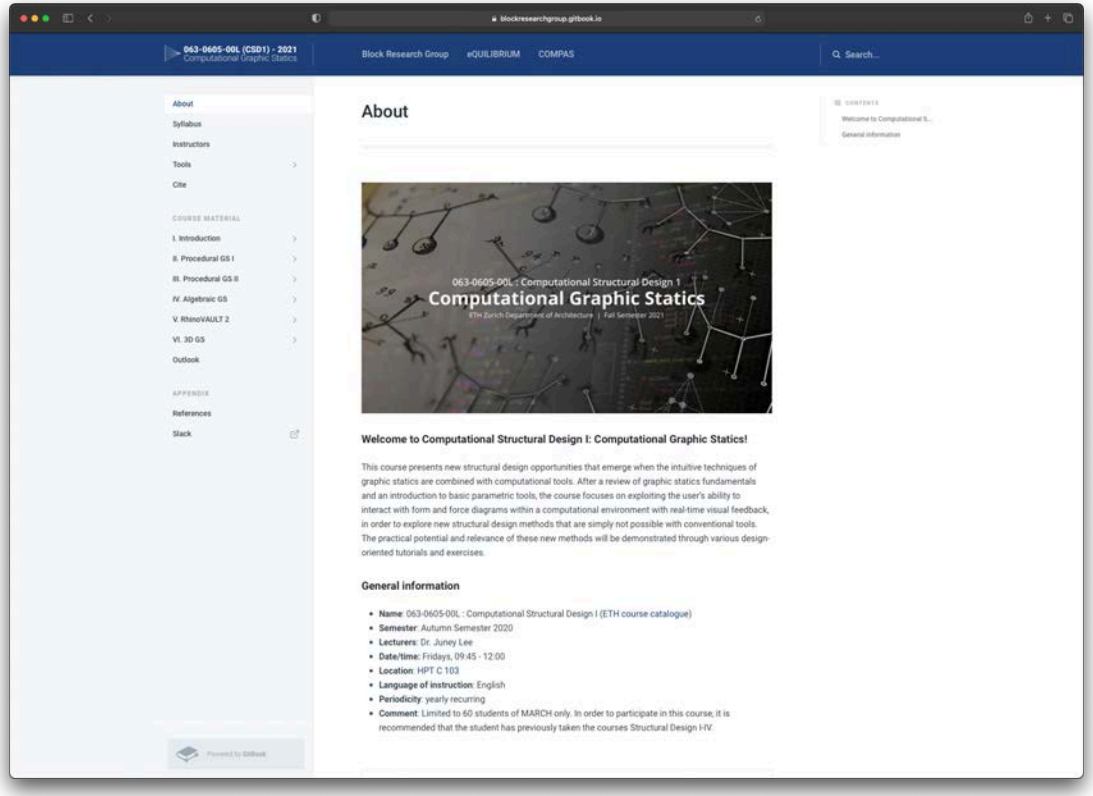
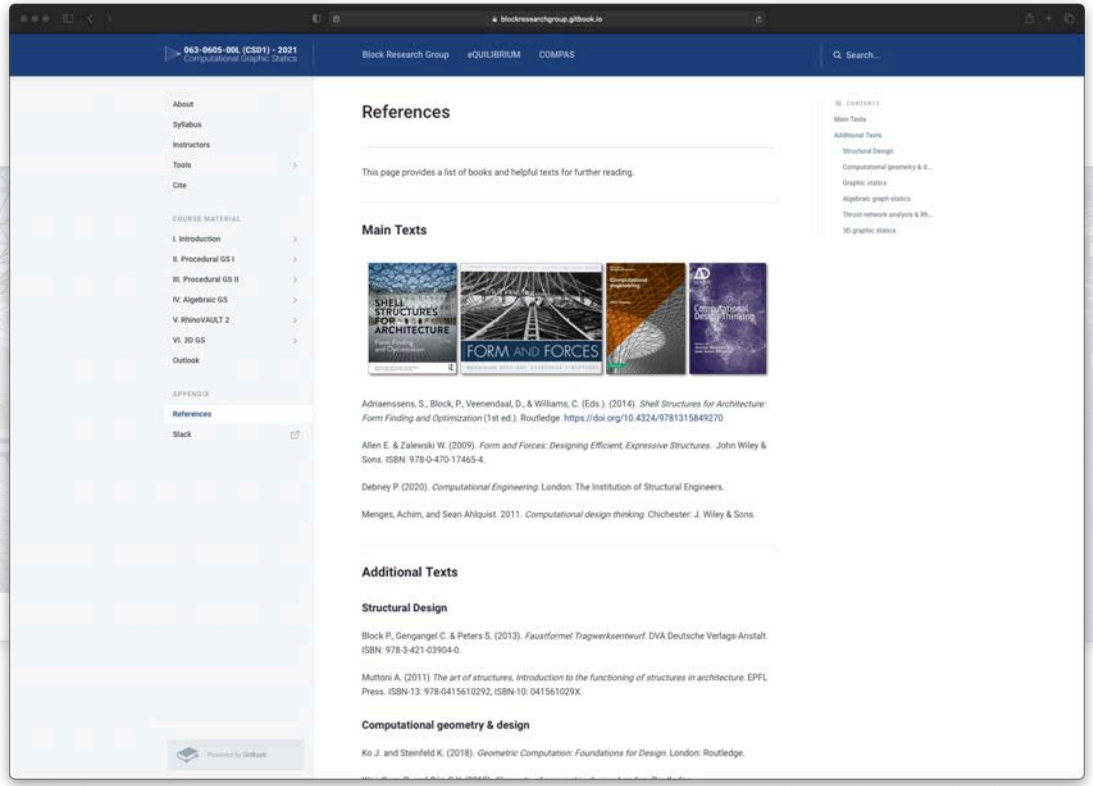
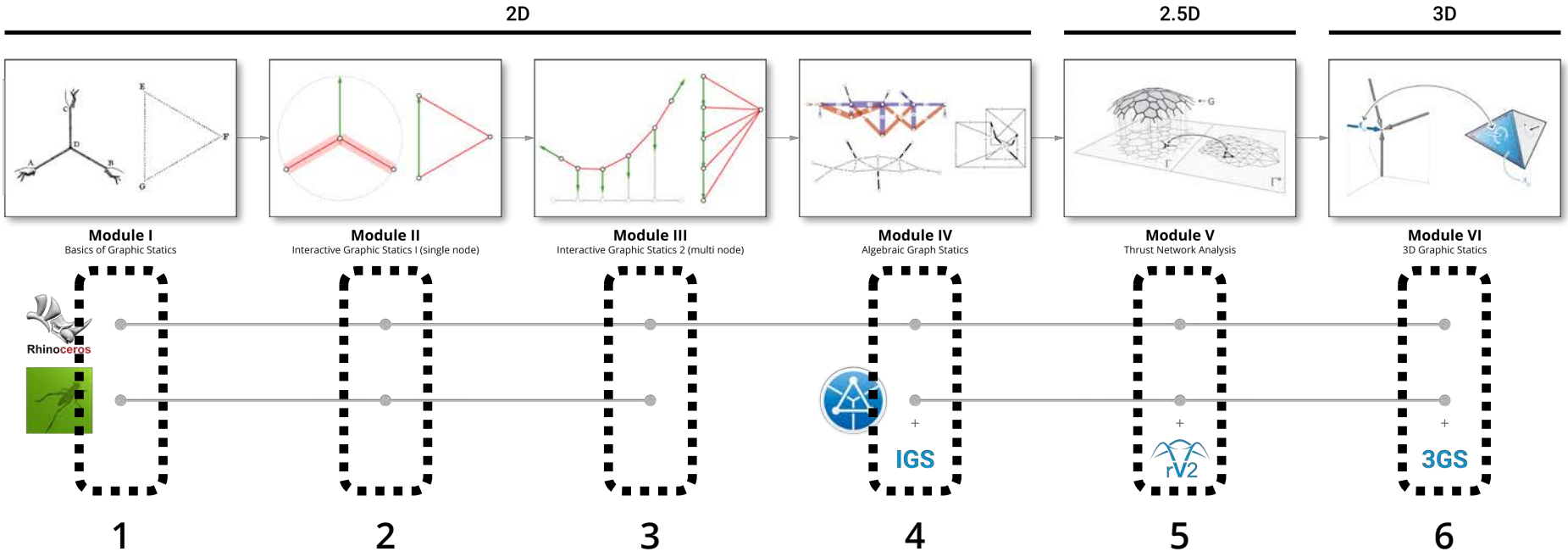


Course website ⟶ https://blockresearchgroup.gitbook.io/csd1-2021



Course references ⟶ “Reference” section on course GitBook

eQUILIBRIUM ⟶ https://block.arch.ethz.ch/eq/


2D
2.5D
3D
Module I
Basics of Graphic Statics
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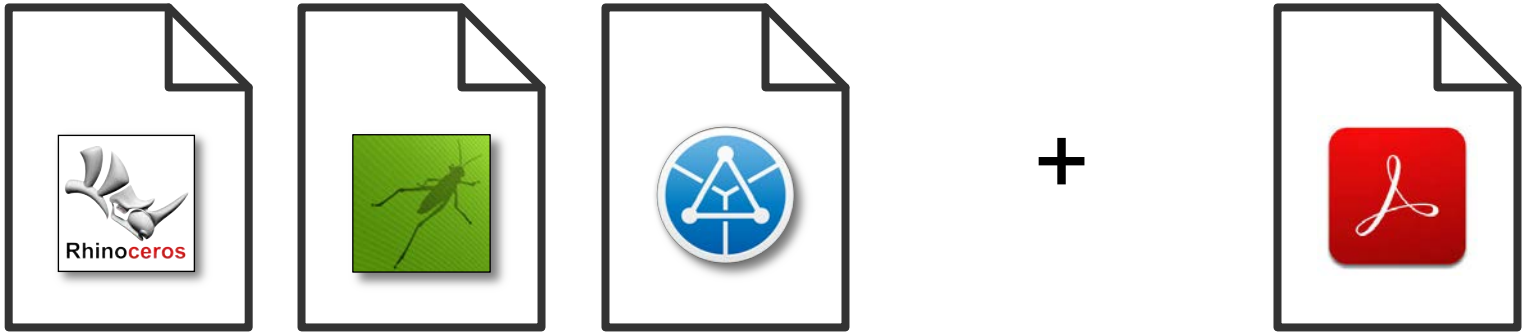


Skill

Understanding

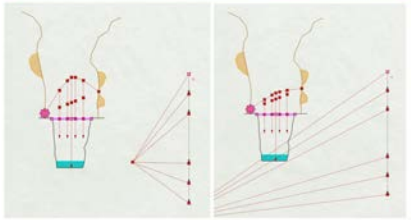
CSD1_FS2020 10/27/20 9:33 PM

3.
The basic idea is to construct the limitations and let rhino show the warning by displaying a symbol at the footage if either of the 3 conditions is not satisfied.

1)To constrain the inclination on the left side: First, input the limit angles X, Y as number sliders and then use the "Rotate" components to translate them into vectors. Starting from the point A on force diagram, use "Line SDL" to draw two constrain lines based on those vectors and get two intersection points with the vertical line (let's name them as point "Bx" and point "By")in the force diagram. Deconstruct the two points and the top point which represents the first force line. By calculating those Y-coordinates (substrate them in pairs and then multiply the results and then to see if it positive or negative) one could easily inspect if the top point lies in between the two points-"Bx"and"By".

2)To examine if the horizontal components at the left footage: Input the Z value and compare it with the distance of point A to the vertical line. (Deconstruct the point A and calculate the difference between the X-components of point A and the vertical line)

3)To exclude the tension situation: one could simply limit the allowable value of inputted X and Y value: all must bigger than "0".

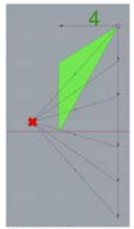


3

CSD1_HS2020 September 2, 2020 10:16 AM

3.
The maximum horizontal force is defined by a parallel line to the load line from the force diagram. This line moves to the left, according to the maximal load set in the „max Horizontal support" component. The angles, in wich the support can be, can be controlled with the two other components (angle 1 and angle 2).
The move component is defined by the motion in „Unit x" (because the line needs to be moved along the x axis) and a reverse component (so the vector turns negative).
Angle 1 and 2 are defined by a rotation.
Angle 1 is the rotation of the direction of the load-line.
Angle 2 is the the rotation from angle 1.
The direction and the size of the support forces are in this case A and B.

Is the support force A inside the green surface, so the direction of the support force is ok, for the defined angles of Angle 1 and Angle 2.
Is the pole inside the green surface, the direction and the size of the maximal horizontal component are ok for the set parameters.



Direction of the support force inside the set parameters, but the set horizontal component is too small (or the geometry of the bridge too shallow)

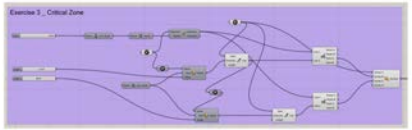
Direction of the support force inside the set parameters. horizontal component also inside the set parameters —> no cross at the pole

2

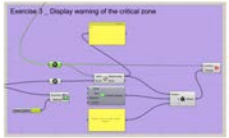
CSD1_FS2020 10/29/20 11:42 PM

The result of the division can not be a round number because in the way I proceeded it will always be an odd number, that's why a used the *Round* component. I then linked the result with *index* output of the *List Item* which is also connected to the *Panel* component of the force magnitudes.
I finally connected the final List to the existing *Amplitude* component. That way I managed to add the force in the middle of the bridge.

Part 3 - Modify the parametric model to provide solutions only in the feasible design space.



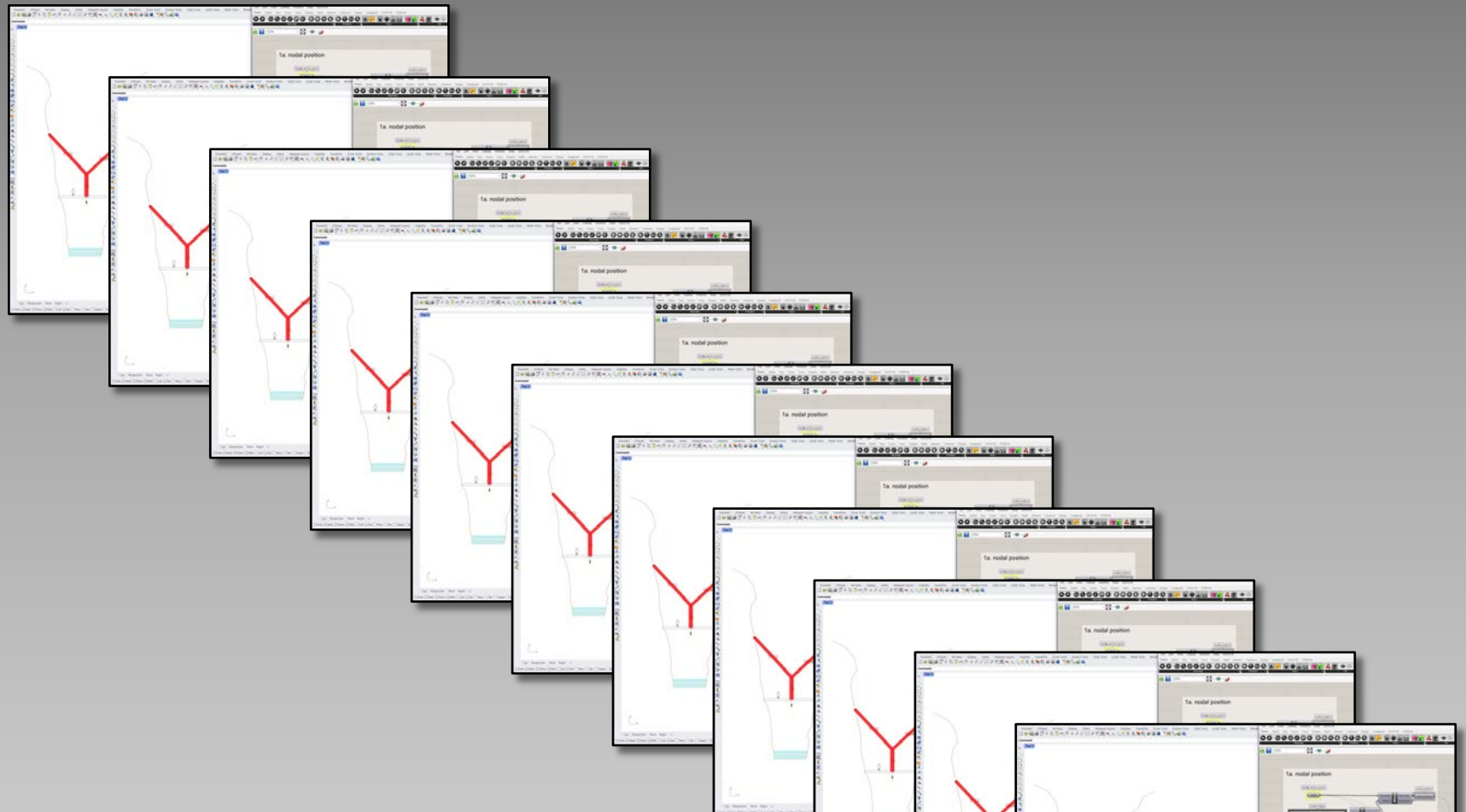
To create the asked limitation we start by adding the *Hmax, angle a* and *angle b* values with a number slider.
The Hmax number slider connected to the *Move* component will define the intensity of the movement of the geometry according to the chosen Hmax value. Same for the angles a and b, which are connected the the *Rotate* components. The two angles linked to the Z unit Axis define the rotation of the vector line.

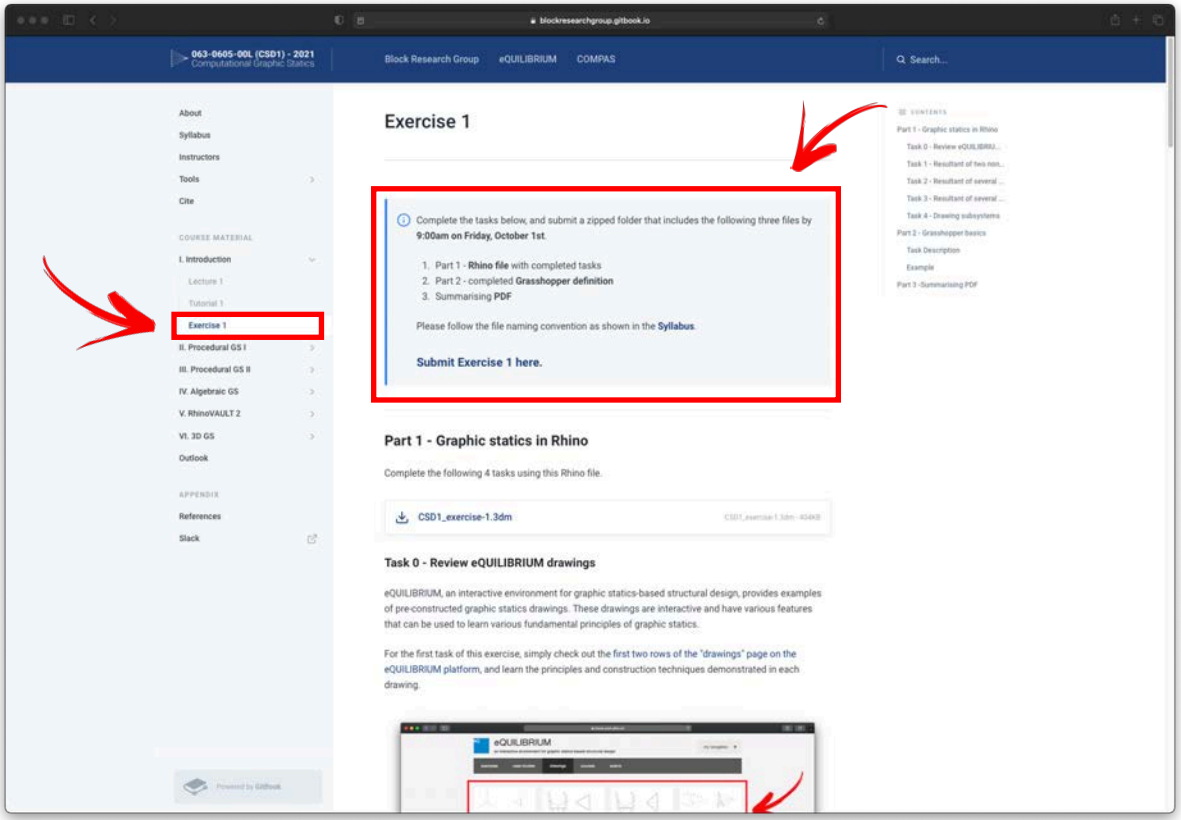


With the Line SDL component I created the vectors starting from the initial point in the force diagram which followed the defined direction of the previous *Rotate* component. The Line / Line component allowed me to create the intersecting points between the two vectors of the angles and the line defined by Hmax.
I finally used the *4 point Surface* component to link the the line defined by the Hmax and the two vector lines of the angles in order to get the feasible region.

In order to be informed when the anchors are not anymore in the feasible zone (out of the defined surface from the previous point) I created a warning display.

2


1a. nodal position


063-0605-00L (CSD1) - 2021
Computational Graphic Statics
Block Research Group
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COMPAS
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III. Procedural GS II
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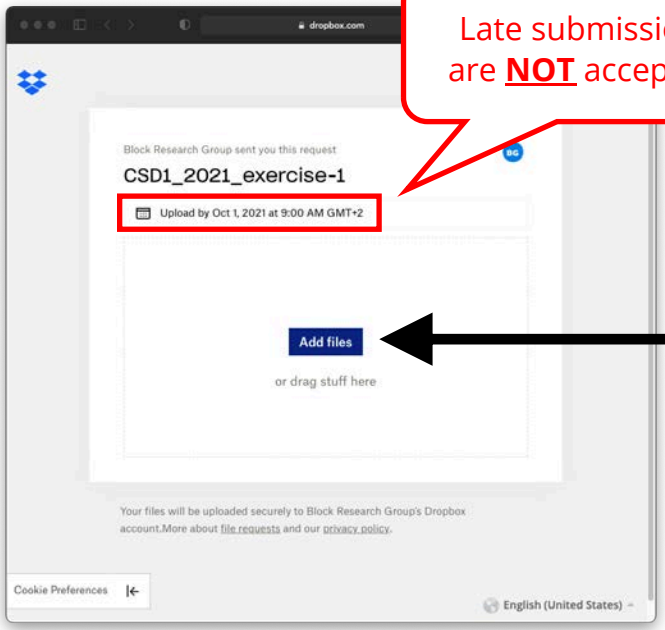
V. RhinoVAULT 2
VI. 3D GS
Outlook
APPENDIX
References
Slack
Exercise 1
Complete the tasks below, and submit a zipped folder that includes the following three files by 9:00am on Friday, October 1st.
1. Part 1 - Rhino file with completed tasks
2. Part 2 - completed Grasshopper definition
3. Summarising PDF
Please follow the file naming convention as shown in the Syllabus.
Submit Exercise 1 here.
Part 1 - Graphic statics in Rhino
Complete the following 4 tasks using this Rhino file.
CSD1_exercise-1.3dm
Task 0 - Review eQUILIBRIUM drawings
eQUILIBRIUM, an interactive environment for graphic statics-based structural design, provides examples of pre-constructed graphic statics drawings. These drawings are interactive and have various features that can be used to learn various fundamental principles of graphic statics.
For the first task of this exercise, simply check out the first two rows of the "drawings" page on the eQUILIBRIUM platform, and learn the principles and construction techniques demonstrated in each drawing.
eQUILIBRIUM

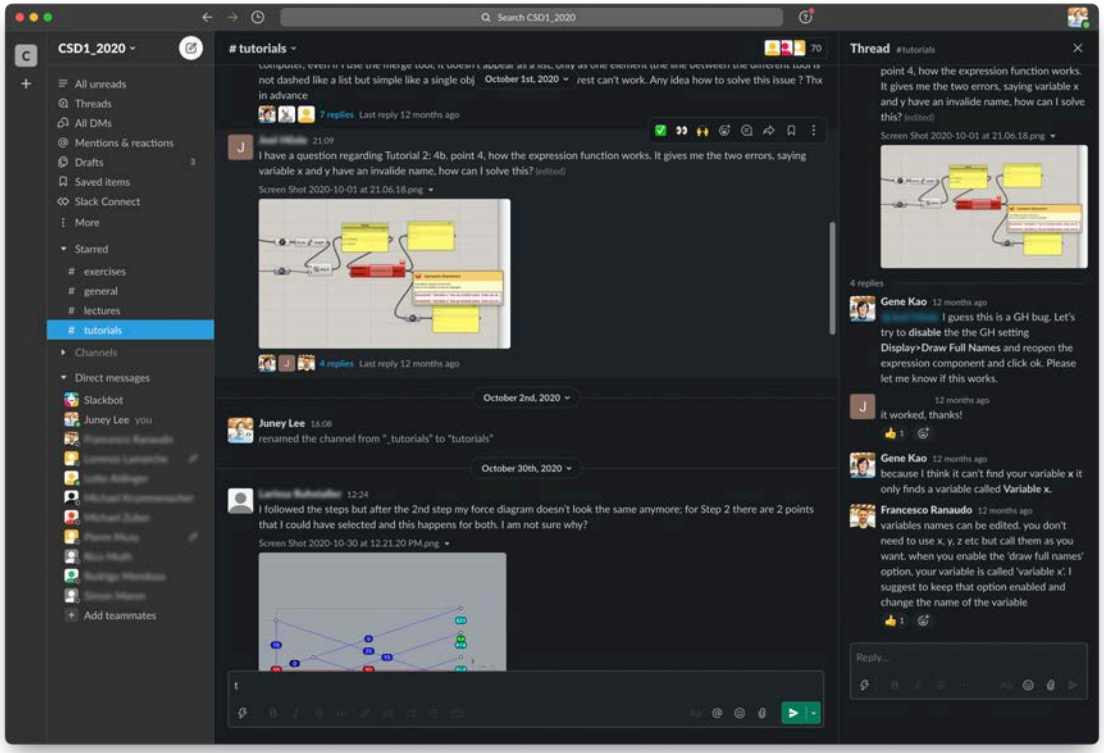


Late submissions are **NOT** accepted!

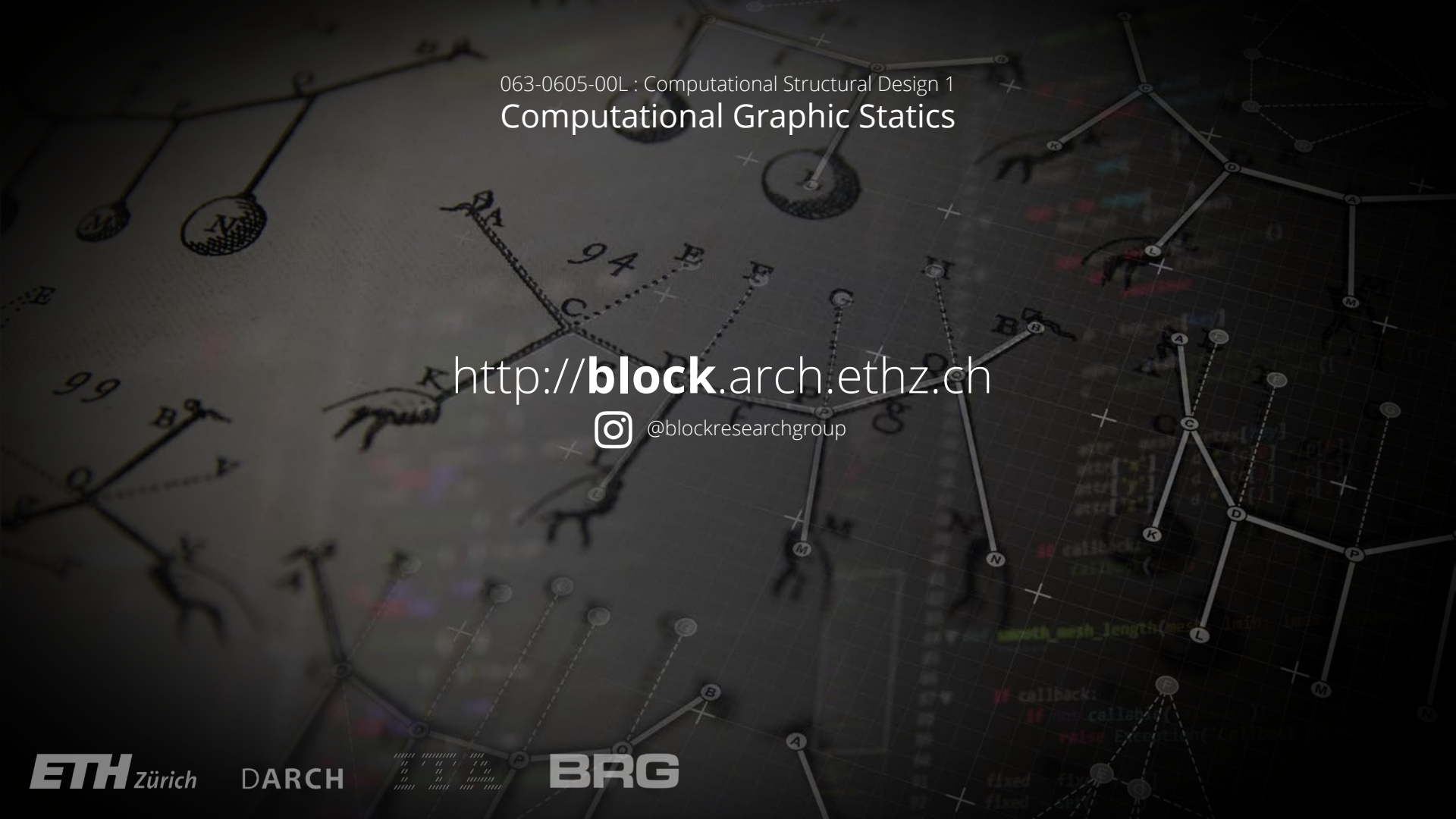
File naming convention

exercise-number_item-number_firstname-lastname.extension

- exercise-1_jane_smith.zip
  - exercise-1_task-1_jane-smith.3dm
  - exercise-1_task-1_jane-smith.gh
  - exercise-1_task-2_jane-smith.3dm
  - exercise-1_task-2_jane-smith.ags
  - ...
  - exercise-1_jane-smith.pdf



Course website ⟶ Link provided on the course GitBook



063-0605-00L : Computational Structural Design 1

Computational Graphic Statics

http://**block**.arch.ethz.ch

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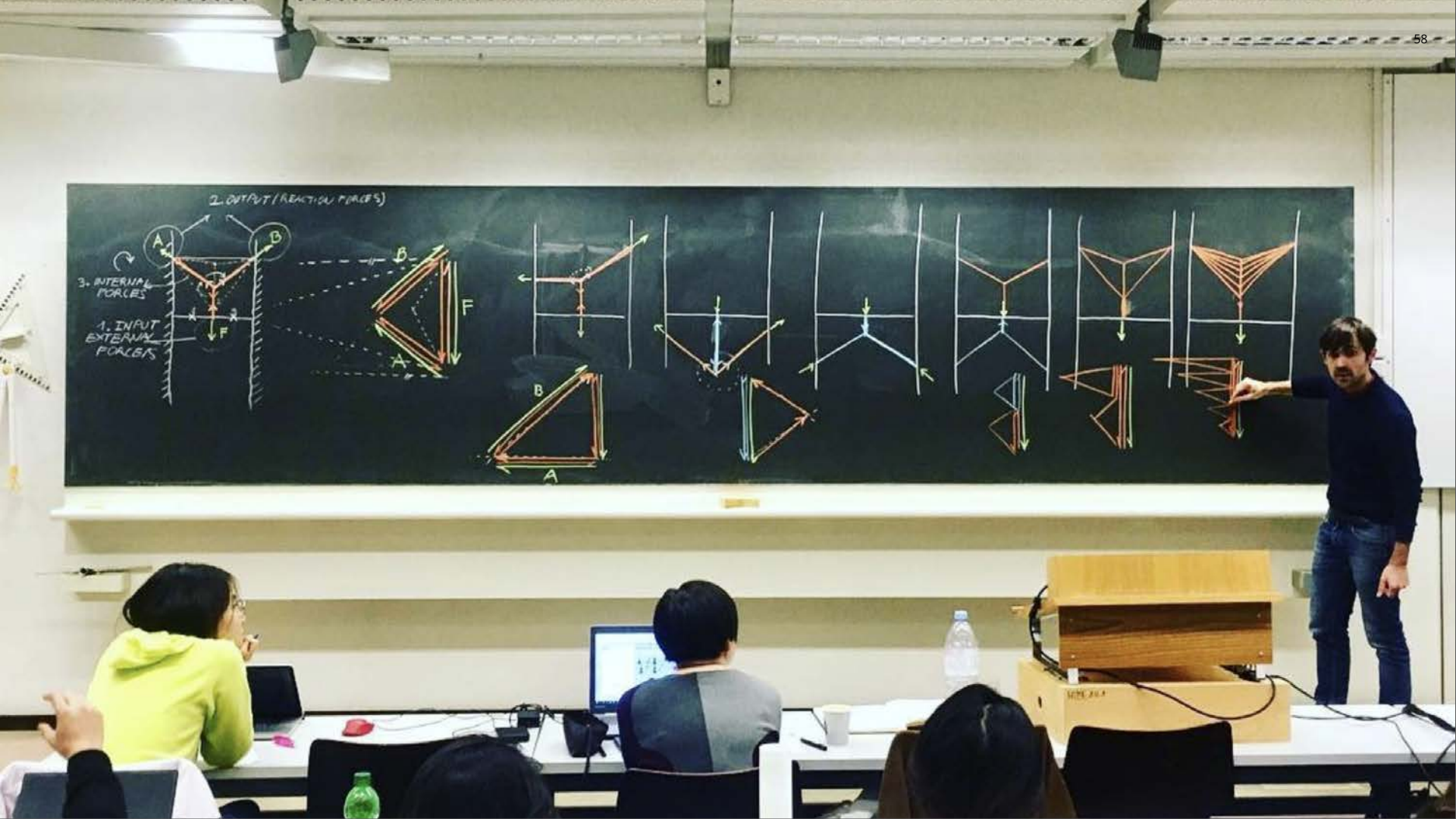
ETH Zürich DARCH BRG


2. OUTPUT (REACTION FORCES)
A
B
3. INTERNAL FORCES
1. INPUT EXTERNAL FORCES
F
B
A
F
B
A